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THE NEW ZEALAND

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Editor: N. A. Marris, M.Sc., B.Com. (Assistant Editor: A. J. Healey, M.Agr.Sc.) Department of Scientific and Industrial Research, Wellington

VOL. 30. SEC. A DECEMBER, 1948 NUMBER 4

THE EFFECT OF STEAM AND CHLOROPICRIN TREATMENT ON THE AMMONIA AND NITRATE NITROGEN CONTENT OF A NELSON TOMATO SOIL

By E. B. KIDSON, Cawthron Institute, Nelson

(*Received for publication, 29th September, 1948*)

Summary

As part of an investigation into the effect of soil-sterilization on the growth and yield of tomato plants, pot experiments were carried out over a period of seven months to determine the effect of chloropicrin and steam treatments on the ammonia and nitrate content of a Nelson tomato soil, with and without fertilizer. It was found that steam sterilization was more effective than the chloropicrin treatment in raising the level of available nitrogen in the soil. Chloropicrin at the rate used (4 ml. to 26 lb. of soil) was shown to delay nitrification some two months longer than steam.

FOLLOWING on the work carried out by Russell and others at the Rothamsted Experimental Station (1), the use of steam for the partial sterilization of tomato soils was introduced in the Nelson district some 20 years ago, and has now become a standard glasshouse practice, repeated tests at the Cawthron Institute having shown the considerable increase in growth and yield associated with steam sterilization.

In recent years chloropicrin has been used with great success in the U.S.A. for the sterilization of intensely-cropped soils. Experiments to determine the effectiveness of chloropicrin-treatment of the soil in Nelson tomato houses have given satisfactory results, comparable to those obtained with steam. The use of chloropicrin has resulted in a great improvement in growth and an increase of about 3 lb. per plant in yield.

The exact role of steam and chloropicrin in causing such a marked increase in growth and yield is not known. The elimination of soil-borne diseases must play an important part. Chemical and physical changes brought about by the action of the sterilizing agent and by the alteration in the soil population after sterilization have not yet been fully elucidated. Russell and many later workers (1) have demonstrated that sterilization has an important effect on the nitrogen supply of the plant. Partial sterilizarion of the soil with steam and certain chemicals is followed by a rise in ammonia nitrogen in the soil. Nitrification however is inhibited for a period the length of which depends on the sterilizing agent. During this period ammonia formed in the soil or added as fertilizer remains as ammonia and is not changed to nitrate as in unsterilized soils.

It was considered that information of the amount of nitrogen present as ammonia and nitrate in Nelson tomato soil under different methods of treatment would be of value in a study of the effect of soil sterilization on the yield and growth of tomato plants. The present paper gives an account of pot experiments to determine the effect of steam-sterilization and chloropicrin-treatment on the ammonia and nitrate nitrogen in a soil of the type on which most of the Nelson tomato houses are located. The soil is characterized by a fairly heavy texture, a pH of about 7 and a high content of exchangeable calcium and magnesium. The phosphate and potassium tend to be low though fertilizer treatment has raised the phosphate content to a high figure in places. In most parts the soil is low in organic matter. The sample of soil used for the pot experiments contained 17.3 m.e. per cent. of calcium, 7.6 m.e. per cent. of magnesium and less than 0.1 m.e. per cent. of potassium. The pH was 7.1 and the organic carbon and nitrogen were 1.65 and 0.17 per cent. respectively. The amount of P_2O_5 soluble in 1 per cent. citric acid was 0.14 per cent.

EXPERIMENTAL

Glazed earthenware pots holding about 26 lb. of soil were used for the experiment. They were divided into two series, (a) without fertilizer and (b) with added fertilizer. Both series contained four pots of unsterilized soil, four of steam-sterilized soil and four of chloropicrin-treated soil. The steamed soil was sterilized in bulk in the usual way on 6th June, 1947. Where chloropicrin was used it was applied in each plot to a depth of 6 in. at the rate of 4 ml. per plot of 26 lb. of soil. The chloropicrin treatment was carried out on 13th June and the pots were then left covered for several days.

In the fertilizer series the fertilizer was thoroughly mixed with the soil. The date of application was 13th June, (before the chloropicrin treatment) and the rate was 2 oz. per pot of a mixture containing superphosphate eight parts, sulphate of potash four parts, sulphate of ammonia one part and dried blood one part, supplying approximately 115 p.p.m. of nitrogen.

Late in June all pots were brought to a moisture content of 60 per cent. saturation and the soil mixed. Water was given periodically throughout the experiment to maintain a weight equivalent to 60 per cent. saturation, tap water being used throughout. The pots were kept free of weeds.

Sampling of the 0-6 in. depth for the estimation of ammonia and nitrate nitrogen was commenced about a month after the application of the fertilizer and continued at intervals until the middle of January. The samples were all taken between 8.30 a.m. amd 9.30 a.m. and the analyses carried out immediately. Three cores were taken from each pot to a depth of 6 in. with a cylindrical soil borer, which was a half inch in diameter. The soil not used for analysis was replaced in the pots.

METHODS OF ANALYSIS

The nitrate nitrogen was estimated by the phenoldisulphonic acid method and the ammonia by extraction with neutral 10 per cent. KCl and distillation with magnesia.

RESULTS

The results obtained are given in Table I and are shown diagrammetically in Figs. 1, 2 and 3.

TABLE I. EFFECT OF STEAM AND CHLOROPICRIN STERILIZATION ON THE AMMONIA AND NITRATE NITROGEN CONTENT OF A NELSON SOIL WITH AND WITHOUT FERTILIZER

I. NO FERTILIZER SERIES. Parts Per Million of Nitrogen on Dry Soil

Date of Sampling.	10/7/47	23/7	5/8	25/8	8/9	22/9	6/10	20/10	11/11	24/11	8/12	30/12	12/1/48
(a) *Ammonia Nitrogen*													
Unsterilized	4	3	2	1	2	1	1	2	3	5	4	2	2
Steam-sterilized	13	18	10	5	4	2	1	3	3	10	4	3	3
Chloropicrin-sterilized	8	14	12	14	15	12	9	8	4	11	5	3	3
(b) *Nitrate Nitrogen*													
Unsterilized	9	8	9	7	8	7	7	7	15	15	11	11	15
Steam-sterilized	7	8	17	23	29	26	26	28	44	36	35	32	35
Chloropicrin-sterilized	7	9	7	6	6	5	7	16	27	26	22	18	28

II. FERTILIZER SERIES. Parts Per Million of Nitrogen on Dry Soil

Date of Sampling.	14/7/47	25/7	7/8	27/8	10/9	24/9	8/10	22/10	13/11	25/11	9/12	29/12	13/1/48
(a) *Ammonia Nitrogen*													
Unsterilized	25	4	3	2	2	2	1	2	6	4	4	1	4
Steam-sterilized	91	93	79	22	7	5	1	3	4	2	3	4	4
Chloropicrin-sterilized	66	67	69	75	82	72	50	41	13	7	4	4	4
(b) *Nitrate Nitrogen*													
Unsterilized	62	67	69	92	94	61	74	60	64	61	59	58	55
Steam-sterilized	7	10	16	80	95	80	79	87	74	65	67	64	62
Chloropicrin-sterilized	9	8	7	7	5	9	31	48	62	61	61	71	69

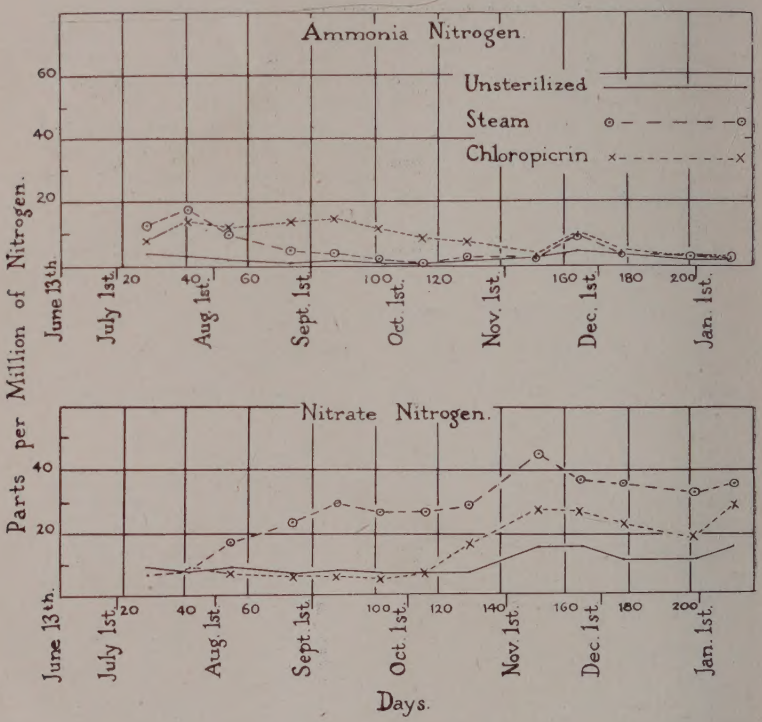

FIG. 1

NO FERTILIZER SERIES

AMMONIA NITROGEN.

In the unsterilized soil the ammonia nitrogen remained very low throughout the experiment, never exceeding 5 p.p.m. Steam treatment caused a slight rise to 18 p.p.m. in July, followed by a drop to figures comparable with those of the unsterilized soil. Chloropicrin treatment produced a similar rise, the increased ammonia content being maintained some two months longer.

NITRATE NITROGEN.

Steaming brought about an appreciable increase in the nitrate nitrogen content over that of the unsterilized soil, presumably owing to increase in bacterial activity. Thus on 8th September, the unsterilized soil contained 8 p.p.m. and the steam-sterilized soil 29 p.p.m. and on 11th November the corresponding figures were 15 p.p.m. and 44 p.p.m. A similar but smaller effect was produced in the chloropicrin-treated soil, delayed about two months owing to the slow re-establishment of nitrification with the chloropicrin treatment. The maximum nitrate nitrogen figures reached in the unsterilized, steam-sterilized and chloropicrin-treated soils were 15 p.p.m., 44 p.p.m. and 28 p.p.m. respectively. For all treatments a rise in nitrate occurred in the October-November period, followed by a slight drop in December.

TOTAL NITRATE AND AMMONIA NITROGEN.

The effect of steam and chloropicrin in raising the level of ammonia plus nitrate in the soil can be clearly seen in the no-fertilizer series in Fig. 3. The increase brought about by both these methods was apparent from the time of the first sampling on 10th July, i.e. 34 days after steaming and 27 days after the application of chloropicrin. The chloropicrin treatment was less effective in this respect than the steaming. Throughout the experiment available nitrogen formed as a result of the chloropicrin treatment was about half that produced by the steam sterilization. Some of this increase may be due to the decomposition of chloropicrin residues in the soil. The amount applied contained nitrogen equivalent to about 50 p.p.m. but considering the volatility of chloropicrin, it is expected that most of this 50 p.p.m. was lost by evaporation.

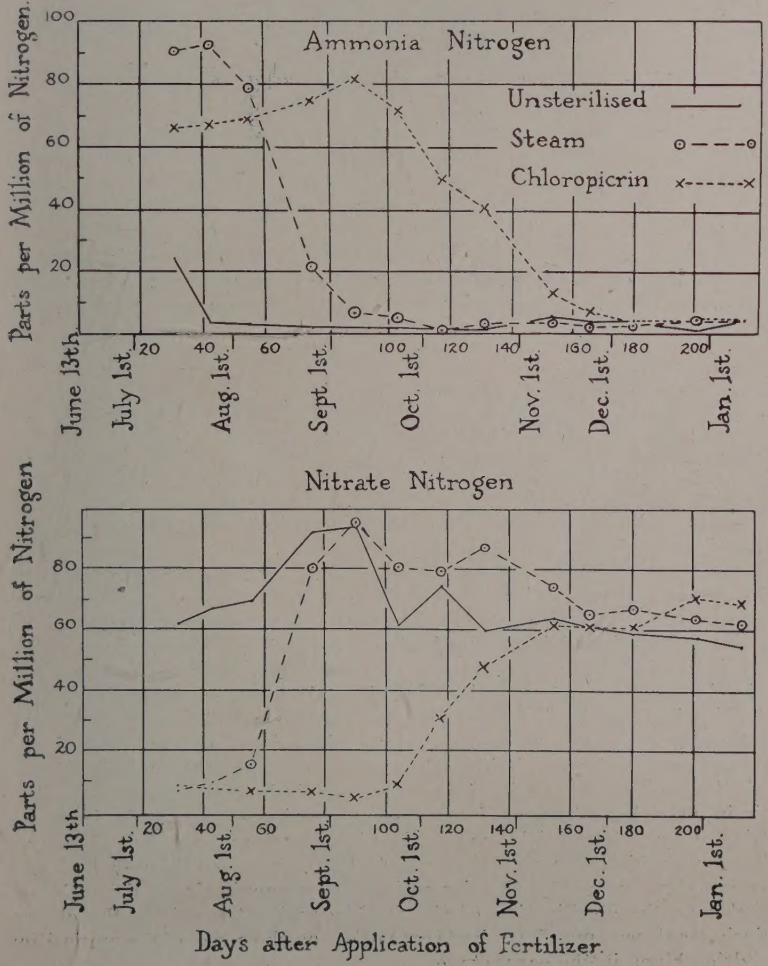

FIG. 2

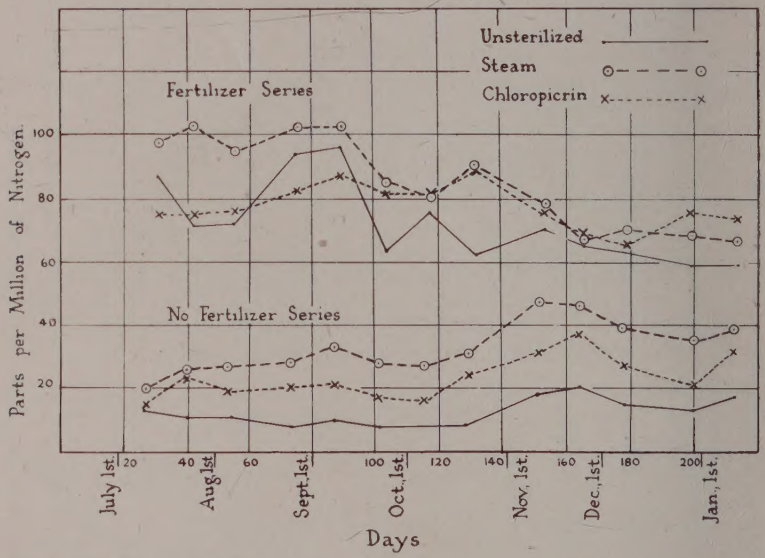

FIG. 3

FERTILIZER SERIES

The fertilizer used supplied nitrogen equivalent to approximately 115 p.p.m., 70 p.p.m. in the form of sulphate of ammonia and 45 p.p.m. as dried blood.

AMMONIA NITROGEN.

The fertilizer was applied on 13th June and by 14th July, at the time of the first sampling, nitrification was almost complete in the unsterilized pots. Only 25 p.p.m. of ammonia nitrogen was found, and this dropped rapidly to a very low figure. For the steamed pots the first figures were high (91 and 93 p.p.m.) but in six to seven weeks from the date of the application of the fertilizer, a rapid decrease had begun, and the ammonia nitrogen dropped to, and remained at that of the unsterilized pots. Allowance being made for the seven days between the steam and chloropicrin treatments, it will be seen that the chloropicrin delayed nitrification considerably longer, a result in agreement with that obtained with the unfertilized soil. Thus the ammonia nitrogen fell to less than 10 p.p.m. in about 40 days after the fertilizer application where no sterilization was given, in 80 to 90 days with steam-sterilization and in 160 days with the chloropicrin treatment. It was noticeable that even when the normal nitrifying power of the soil appeared to be restored, nitrification was slower in the chloropicrin-treated soil than the steamed soil. There are some indications also that chloropicrin may have slowed down the production of ammonia from the dried blood. The initial ammonia nitrogen figure on 14th July was 66 p.p.m. which showed a slow rise to 82 p.p.m. over the next 58 days, presumably owing to the formation of ammonia from dried blood. However, the sterilization of the fertilizer with the soil in the chloropicrin treatment may have had some effect on the speed of decomposition of dried blood in the early stages.

NITRATE NITROGEN.

By 14th July the unsterilized soil had a nitrate nitrogen content of 62 p.p.m. which rose to a maximum about the beginning of September. In the steam- and chloropicrin-sterilized soils the nitrate nitrogen content at the first sampling was 7 and 9 p.p.m. respectively, but with the steam-treatment analyses showed a rapid formation of nitrate commencing about 20 days later, and corresponding to the fall in ammonia content. In the chloropicrin-treated pots the formation of nitrate from the ammonia of the fertilizer was delayed approximately a further 50 days and was slower than where steam had been used.

TOTAL NITRATE AND AMMONIA NITROGEN.

For the fertilizer series (Fig. 3) the steamed soil had a higher content of available nitrogen throughout the experiment than did the unsterilized soil. In the chloropicrin-treated soil the available nitrogen did not rise above that of the unsterilized soil until late September, after which steam and chloropicrin gave almost identical values. It is of interest to note that in the fertilizer series the nitrogen present as nitrate and ammonia did not at any time reach 115 p.p.m., the amount actually supplied by the fertilizer. Also in both sterilized and unsterilized pots of this series there was a slow decrease after the middle of September. Analysis showed that this decrease could not be explained by leaching of nitrate into the soil below the usual sampling depth. It is presumed to be due to the removal of available nitrogen by algae and other micro-organisms.

CONCLUSION

It appears that chloropicrin at the rate used, (somewhat higher than the local commercial rate) is not as effective as steam in raising the level of easily available nitrogen in the soil. Thus, in the unfertilized soil, steam-sterilization brought about an increase of some 20 p.p.m. of nitrogen and chloropicrin-treatment approximately 10 p.p.m., some of which may have been due to the decomposition of chloropicrin residues in the soil.

The nitrifying power of the soil was more affected by the chloropicrin-treatment than by the steam-sterilization. Where chloropicrin had been used, ammonia formed in the soil as a result of sterilization began to change to nitrate about two months later than in steamed soil. A similar effect was observed in the nitrification of the ammonia from applied nitrogenous fertilizers. It is to be expected that different results would be obtained with different quantities of chloropicrin.

ACKNOWLEDGMENT

The author gratefully acknowledges the assistance given by Mr. J. Robinson and Mr. E. Marshall in carrying out this work.

REFERENCE

(1) RUSSELL, E. J and HUTCHINSON, H. B. (1909): *J. Agr. Sci.*, *3*, 3.

CHEMICAL CONTROL OF *OXYCANUS CERVINATUS* WALKER

IV. EXPERIMENTS IN 1947 SEASON

By L. J. DUMBLETON, J. M. KELSEY and J. M. HOY, Entomology Division, Department of Scientific and Industrial Research, Nelson

(*Received for publication, 31st December, 1947*)

Summary

No equally cheap, efficient and readily available substitute for bran in the Paris Green-bran bait has been discovered. Gristed oats gave partial control but was more costly and presented problems in mixing and spreading. The addition of 2½ lb. of wheat germ to 50 lb. of sawdust or chaff improved their attractiveness as carriers. D.D.T. in dosages of 0.6 lb. of the para para isomer per acre gave good control, both as sprays and as dusts. Gammexane dusts, at an equivalent dosage of the gamma isomer per acre, gave equally good control of *Oxycanus cervinatus*.

THE poisoned bran bait which was developed for the control of subterranean grass caterpillar in pasture by Dumbleton and Dick (1, 2, 3) has proved to be effective and reasonably cheap, especially on pastures devoted to grass and clover seed production. Supplies of bran are, however, always limited and at present are controlled. Farmers have been faced with difficulty in securing bran and threatened with prohibition of the use of bran in poison baits for insect control. For this reason an experiment designed to test the effectiveness of possible alternative materials was laid down in the autumn of 1947. The opportunity was also taken to test out the newer organic insecticides applied as dusts and sprays.

LOCATION, LAYOUT, TREATMENTS AND SAMPLING METHOD

The experimental area was a run-out pasture on the Bruce Estate at Seafield, near Ashburton. The experiments were laid out as randomized blocks with three replications of each treatment. The individual plots were ½ chain by ¼ chain (1/80 acre). In Experiment 1 there were no buffer areas between plots or between blocks. In Experiments 2 and 3 there were ¼ chain buffer areas between blocks, but none between plots. The treatments were applied, in Experiments 1 and 2 on 15th March, and in Experiment 3 on 28th March and 2nd April.

Poison baits were broadcast by hand, dusts were applied with a hand dust gun of the plunger type and sprays with a knapsack sprayer.

The details of the experiments are as follows:—

Experiment 1. Poison Baits and D.D.T. Spray (Quantities per Acre)

Treatment No. 1 Paris Green 2 lb. 1 oz.; bran 50 lb.
2 Wettable D.D.T. (20 per cent. p.p.i.) 2½ lb.; water 100 gal.
3 As_2O_3, 2 lb. 1 oz.; bran 50 lb.
4 Paris Green 2 lb. 1 oz.; gristed oats 50 lb.
5 Paris Green 2 lb. 1 oz.; sawdust 50 lb.
6 Paris Green 2 lb. 1 oz.; sawdust 50 lb.; white flour 2½ lb.

7 Paris Green 2 lb. 1 oz.; sawdust 50 lb.; 80 per cent. flour 2½ lb.
8 Paris Green 2 lb. 1 oz.; sawdust 50 lb.; high B_1 flour 2½ lb.
9 Paris Green 2 lb. 1 oz.; sawdust 50 lb.; wheat germ 2½ lb.
10 Paris Green 2 lb. 1 oz.; chaff 50 lb.
11 Paris Green 2 lb. 1 oz.; chaff 50 lb.; white flour 2½ lb.
12 Paris Green 2 lb. 1 oz.; chaff 50 lb.; 80 per cent. flour 2½ lb.
13 Paris Green 2 lb. 1 oz.; chaff 50 lb.; high B_1 flour 2½ lb.
14 Paris Green 2 lb. 1 oz.; chaff 50 lb.; wheat germ 2½ lb.
15 Paris Green 2 lb. 1 oz.; coarse gristed oats 50 lb
16 Control.

Experiment 2. D.D.T. Dusts (Quantities per Acre)—

Treatment No. 1 Paris Green 2 lb. 1 oz.; bran 50 lb.
2 Control
3 D.D.T. 2 per cent. (p.p.i.) dust at 120 lb.
4 D.D.T. 2 per cent. (p.p.i.) dust at 60 lb.
5 D.D.T. 2 per cent. (p.p.i.) dust at 30 lb.
6 D.D.T. 2 per cent. (p.p.i.) dust at 15 lb.

Experiment 3. Gammexane Dusts (Quantities per Acre)—

Treatment No. 1 Paris Green 2 lb. 1 oz.; bran 50 lb.
2 Control
3 Gammexane 4 per cent. dust (0.5 per cent. g.i.) 120 lb.
4 Gammexane 4 per cent. dust (0.5 per cent. g.i.) 60 lb.
5 Gammexane 4 per cent. dust (0.5 per cent. g.i.) 30 lb.
6 Gammexane 4 per cent. dust (0.5 per cent. g.i.) 15 lb.

The plots were sampled in mid-May, two months after treatment. Ten samples, each one foot by one foot, were taken at random within each plot and the number of living *Oxycanus* larvae and *Odontria zealandica* larvae were recorded for each sample. Before sampling was commenced the plots were graded for vegetation cover separately by two observers. An arbitrary visual grading was used, "0" being the cover on the worst of the untreated plots and "10" being the cover on the best of the plots treated with the Paris Green and bran bait (Experiment 1, Treatment No. 1).

Experimental Results

The data relating to surviving *Oxycanus* caterpillars which were subjected to an analysis of variance reveals that there are significant treatment effects. The differences in treatment means required for significance are 3.41 on the 5 per cent. level and 4.59 on the 1 per cent level.

TABLE I. EXPERIMENT 1. POISON BAITS AND D.D.T. SPRAY

Treatment No.	No. of living *Oxycanus* caterpillars per sq. ft.			Treatment Mean	No. of living *O. zealandica* larvae per sq. ft.			Treatment Mean	Grading of Vegetation cover after treatment.			Treatment Mean
	Block.				Block.				Block.			
	A	B	C		A	B	C		A	B	C	
1	1.2	1.1	2.8	1.66	11.1	37.4	39.6	29.36	9	8	8	8
2	6.1	3.1	2.7	3.96	24.3	44.3	18.4	29.0	8	8	10	8
3	11.5	7.0	11.5	10.0	30.0	20.0	19.6	17.52	1	1	1	1
4	8.1	6.0	5.4	6.50	8.3	22.4	21.7	17.46	4	5	4	4
5	11.4	7.2	12.3	10.30	9.7	15.3	24.1	16.36	1	1	0	0.6
6	10.2	9.1	8.9	9.40	6.3	20.5	14.4	13.73	2	1	1	1
7	13.7	7.2	9.9	10.26	16.0	25.1	34.8	25.3	1	1	1	1
8	15.8	10.7	8.6	11.70	3.0	10.1	11.0	8.03	2	1	2	1
9	7.6	8.3	4.2	6.70	11.3	10.8	9.2	10.43	4	3	8	5
10	14.1	9.0	4.8	9.30	9.9	6.0	27.8	14.56	0	1	5	2
11	12.0	7.4	7.7	9.03	1.1	14.5	35.6	17.36	2	3	3	2
12	7.5	4.5	9.5	7.16	2.8	21.4	21.0	15.06	3	3	3	3
13	9.8	7.1	5.9	7.60	12.9	37.0	31.4	27.10	2	4	4	3
14	4.5	6.7	7.6	6.26	5.9	21.2	41.7	22.93	4	5	3	4
15	3.9	3.3	3.7	3.30	9.7	35.7	9.4	18.26	6	8	9	7
16	8.2	7.3	7.0	7.50	6.0	25.8	24.6	18.80	0	3	0	1

On these criteria, Treatments Nos. 2 and 15 are significantly better than the control at the 5 per cent. level and Treatment No. 1 is significantly better at the 1 per cent. level.

The pasture on which the experiments were situated was infested with both *Oxycanus cervinatus* and *Odontria zealandica*. The damage done to the pasture by the root-feeding larvae of *O. zealandica* could affect the percentage cover gradings by which was assessed the response of *O. cervinatus* to the treatments. The data on larval populations of *O. zealandica* are therefore included in Tables I, II and III for reference. The treatments were not expected to affect *O. zealandica*, and there is no indication that they did so.

The vegetation cover gradings correlate reasonably well with the surviving *Oxycanus* population and there are no obvious anomalies in this correlation on individual plots which had large populations of *O. zealandica*.

Another factor which may account for anomalous results is the possible migration of *Oxycanus* larvae due to starvation, from control plots, untreated areas or plots on which the treatments were ineffective, on to plots where the treatment was effective and resulted in a greater vegetation cover.

Whatever the difficulties in interpretation of the *Oxycanus* population figures, the final criterion of effectiveness of the treatments must be the persistence or recovery of the pasture. Judged on this basis, it is evident that the D.D.T. spray gave results as good as the Paris Green-bran bait which was used as a standard. Gristed oats was noticeably better than the controls but not as good as Paris Green-bran or D.D.T. The other indication which is of some interest is that the addition of wheat germ to both sawdust and chaff appears to improve the attractiveness of these normally unattractive materials.

TABLE 2. EXPERIMENT II. D.D.T. DUSTS

Treatment No.	No. of living *Oxycanus* caterpillars per sq. ft.			Treatment Mean	No. of living *O. zealandica* larvae per sq. ft.			Treatment Mean	Grading of Vegetation cover after treatment.			Treatment Mean
	Block.				Block.				Block.			
	A	B	C		A	B	C		A	B	C	
1	0.1	0.7	1.0	0.60	24.6	23.7	1.8	16.7	10	10	10	10
2	7.1	10.7	9.4	9.06	23.2	8.5	1.6	11.1	0	2	1	1
3	0.0	0.0	0.0	0.0	31.5	6.8	1.5	13.26	10	11	10	10
4	0.6	0.0	1.1	0.56	11.7	23.1	2.5	12.43	12	10	10	10
5	1.5	1.0	2.2	1.56	15.6	12.6	5.0	11.06	9	10	9	9
6	4.9	3.5	5.3	4.56	20.0	8.1	4.1	10.73	7	8	6	7

An analysis of variance on this section in Table II dealing with *Oxycanus* population shows the existence of significant treatment effects. The differences in treatment means required for significance are 1.65 on the 5 per cent. level and 2.35 on the 1 per cent. level.

All treatments are significantly better than the control on the 1 per cent. level. Only Treatment No. 6 (15 lb. D.D.T. per acre) gave significantly poorer results than the standard Paris Green-bran bait. Differences between the three other D.D.T. dosages were not significant.

The treatment means for *Oxycanus* population correlate well with those for vegetation cover.

Vegetation cover gradings in excess of 10 in Table II indicate that the plant cover on these plots was better than that on the Paris Green-bran plots which were taken as the standard for comparison.

TABLE III. EXPERIMENT 3. GAMMEXANE DUSTS

Treatment No.	No. of living *Oxycanus* caterpillars per sq. ft.			Treatment Mean	No. of living *O. zealandica* larvae per sq. ft.			Treatment Mean	Grading of Vegetation cover after treatment.			Treatment Mean
	Block.				Block.				Block.			
	A	B	C		A	B	C		A	B	C	
1	7.4	5.1	4.1	5.52	8.5	7.9	1.4	5.93	7	7	5	6
2	11.0	9.8	8.8	9.86	7.2	4.3	2.9	4.80	1	1	1	1
3	1.7	1.1	1.9	1.56	12.0	2.6	8.7	7.76	10	10	9	9
4	3.8	4.4	3.1	3.76	9.2	16.1	1.6	8.96	9	7	9	8
5	10.1	6.7	6.6	7.80	11.9	2.2	6.0	6.70	4	5	4	4
6	11.7	7.9	6.8	8.80	8.8	12.0	3.2	8.00	3	1	1	1

An analysis of variance on the section of Table III dealing with the *Oxycanus* population discloses that there are significant treatment effects. The differences between means required for significance are 1.98 on the 5 per cent. level and 2.82 on the 1 per cent. level.

Treatments Nos. 3 and 4 are significantly better than the control on the 1 per cent. level, Treatment No. 5 is significantly better on the 5 per cent. level and Treatment No. 6 is not significantly better than the control. The *Oxycanus* populations from Treatment No. 1 (the standard Paris Green-bran bait) are much higher than is usual with this treatment, but no cause can be assigned for this unless it is due to migration of larvae from other plots.

DISCUSSION

Experiment 1.

The treatments for trial were compared with an untreated control plot and with a standard Paris Green-bran bait.

The wettable D.D.T. (Treatment No. 2) used at a dosage of ½ lb. of the para para isomer in 100 gallons of water per acre gave excellent results. The cost for material alone of this treatment would be approximately 9/- per acre.

The Paris Green and gristed oats treatment (No. 4) which gave a partial control, would cost for materials alone approximately 14/- per acre. This is based on Paris Green at 3/- per lb., oats ex store at 5/6 per bushel, plus cost of gristing. This bait besides being less effective and more costly than the Paris Green-bran bait, is difficult to mix properly owing to the balling of the fine floury fraction and probably would not run as freely as bran through a top-dresser. Using only the coarser fraction of the gristed oats (Treatment No. 15) which was retained on a $\frac{1}{16}$ inch mesh sieve and constituted approximately half the weight of the whole sample, the cost would be increased to approximately 20/- per acre without any noticeable increase in efficiency.

Treatments Nos. 5-9 and 10-14 constituted an attempt to increase the attractiveness of sawdust and chaff, both of which are unattractive. Since it was considered possible that vitamin B_1 or associated vitamins of the B group might be in part responsible for the attractiveness of bran, four materials of different B_1 content were added to these carriers. The vitamin B_1 content of these was as follows :—

White flour (72 per cent. extraction), 1.7 gammas ; 80 per cent. flour, 3.0 gammas ; wheat germ, 15.0 gammas ; high B_1 flour, 20-25 gammas. Of these materials, wheat germ alone showed any promise and as this was not the highest in B_1 concentration it is presumably some other constituent which is the attractive principle. It has not so far been possible to test the influence of the fats and oils normally occurring in wheat germ and bran on the attractiveness of baits. Wheatgerm is quoted at the same price as flour—about 1.65 d. per pound.

Experiment 2.

In this experiment D.D.T. applied as a dust was tested at different dosages against the standard Paris Green-bran bait.

The results demonstrated that satisfactory control of *Oxycanus* could be secured with quantities as low as 30 lb. per acre of 2 per cent. D.D.T. dust. The results from the 15 lb. per acre dosage were noticeably poorer. This dust was a jet-pulverised dust containing 2 per cent. of the para para isomer of D.D.T. and diluted with equal parts of talc-magnesite and china clay. The talc-magnesite is 60 per cent. talc and 40 per cent. magnesite. This is a dust of very fine particle size. Estimating the visible coverage by the dust after application, it was considered that 120 lb. per acre was wastefully heavy, 60 lb. was a good coverage, 30 lb. was getting too light, and 15 lb. was too light.

The results are more instructive if expressed in terms of para para isomer content. For Treatments Nos. 3, 4, 5 and 6 these are 2.4, 1.2, 0.6 and 0.3 lb. per acre. The lowest satisfactory dosage of 30 lb. per acre or 0.6 lb. per acre of the para para isomer gave similar results to the D.D.T. spray at 0.5 lb. para para isomer per acre in Experiment 1.

This 2 per cent. dust is retailed at 9d. per lb. and at a dosage of 30 lb. per acre would cost 22/6 per acre for materials alone. The necessity for specialised dusting equipment for large scale application is an additional disadvantage.

Experiment 3.

In this experiment the treatments were not applied until 2 weeks after those in Experiments 1 and 2. As the treatment had 6 weeks in which to act it is fair to assume that it had exerted its full effect and that it can be legitimately compared with results from other treatments in Experiments 1 and 2. The gammexane dust gave effective control of *Oxycanus*, but at a relatively higher dosage per acre than the D.D.T. dusts. This dust was given as a 4 per cent. dust containing 0.5 per cent. gamma isomer. The price was quoted as approximately ¼d. per lb. If Treatments Nos. 3, 4, 5 and 6 are expressed as pounds of gamma isomer per acre, these are 0.6 lb., 0.3 lb., 0.15 lb. and 0.075 lb. A dosage of 120 lb. per acre (0.6 lb. g.i.) produced results equivalent to those from 30 lb. per acre (0.6 lb. p.p.i.) of D.D.T., D.D.T. and gammexane in equal dosages of the active isomers appear to be equally toxic to *Oxycanus*. This formulation of gammexane, at a lower active isomer content and a higher cost per pound, is not as economical as D.D.T. It suffers from the same disadvantage as D.D.T. dust in requiring special equipment for application.

CONCLUSIONS

No satisfactory alternative to bran, for use as a carrier in poison baits has been discovered. The use of gristed oats showed some promise, but this material is dearer than bran and subject to disadvantages in mixing and spreading which are not encountered with bran.

Wheat germ showed some promise as an adulterant for otherwise unattractive carriers such as sawdust and chaff, and efforts should be made to isolate and identify the attractive principle in bran and wheat germ, if indeed attractiveness is conferred by a single substance.

D.D.T. and gammexane dusts appeared to be equally effective weight for weight of their active isomers. D.D.T. has an advantage in cost over gammexane, but both require special dusting equipment. A D.D.T. spray at 0.5 lb. of the para para isomer in 100 gallons of water gave effective control at a cost, for materials alone, little in excess of the standard Paris Green-bran bait. If efficient spraying and dusting appliances were available, sprays would probably be preferred on the score of cost but this may be offset by the volume of water required for spraying large areas of pasture. The application of D.D.T. concentrates as aerosols, using very much smaller volumes of liquid per acre, would appear to have considerable promise.

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STORAGE OF CURD FOR PIG-FEEDING
BIOCHEMICAL INVESTIGATIONS

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Summary

To study the biochemical factors involved, curd has been prepared from buttermilk and stored in twenty-one containers of varying sizes for periods of six to eight months. By detailed chemical analyses of the buttermilk, of the curd and especially of the whey produced from it, the progress of changes during preparation and storage has been followed. The results have made clear the basic principles on which practical methods of preparation and storage depend for success. The main bacteriological and chemical changes appear to be quite similar to those which occur in traditional methods of cheese-making.

INTRODUCTION

DURING recent years an increased interest has been taken, especially in northern dairying districts, in the storage of curd made from buttermilk and skim-milk for the purpose of having supplies of this valuable food available in winter for pig-feeding. To provide winter food for both man and animal, various methods of storing dairy produce have been used in many countries from time immemorial. According to Arthur Young, F.R.S., a pioneer of scientific farming, the storage of skim-milk and whey in brick cisterns appears to have been practised in the eighteenth century. In his eighth edition of "The Farmer's Calendar", published in 1809, he recommended this method of storing dairy by-products to provide winter feed for pigs farrowed in the autumn.

Notwithstanding the antiquity of the process, the idea arose in recent years that some very special methods were required to initiate successfully the preparation and storage of curd. This idea was fostered by the fact that some operators stored curd year after year without a failure, while others sometimes succeeded, but at other times failed. Consequently scientific assistance was solicited to study the biochemical problems associated with the preparation and storage of curd from buttermilk or skim-milk. During the 1944-45 dairy season, some preliminary investigations were undertaken at Featherston, and the results of these enabled plans to be made for an extensive series of trials during the 1945-46 season. These trials were carried out at the farm where garbage from the Japanese prisoner-of-war camp was being used for feeding pigs, and where also an ample supply of buttermilk from the local dairy factory was available for use.

The formation or precipitation of curd from buttermilk or skim-milk obviously results from bacterial fermentation of milk sugar, yielding chiefly lactic acid. This dissolves the lime salts naturally combined with casein, which is then precipitated and gradually aggregates together into curd. At first sight it might have appeared desirable to study the bacteria responsible for these changes to try to find out if any particular types were more suitable than others for the purposes desired. However from a knowledge of the biochemistry of milk, it was clear that a variety of milk-souring bacteria were capable of producing such changes, and the results finally yielded by using different types of bacteria might not show

quite as much variation as would be expected. The variations which might occur were chiefly in the time taken to complete the souring process, and those times were also related to the optimum growth temperatures of specific organisms. A knowledge of past researches in dairy bacteriology also indicated that a tremendous amount of work would be required to isolate, and to study one by one in pure culture, various types of milk-scouring bacteria, to find which might be the best for the purpose of preparing curd for storage. Apart from these considerations, the original buttermilk would obviously have a liberal inoculation of a considerable variety of bacteria. It was therefore decided that to attempt any detailed bacteriological work on the curd during preparation and storage would be unprofitable, but instead plans were made to use suitable methods of chemical analysis to follow the changes produced by bacteria. The only bacteriological part of the investigation consisted in providing a substantial inoculation of certain lots of buttermilk with specific types of lactic acid bacteria to find the effect upon the process and the finished product. To enable comparisons to be made a series of containers of various sizes were procured in which to prepare and store curd under various conditions. The lay-out of these containers is shown in the first illustration accompanying the practical description already published (1). A programme of analytical work was mapped out, and although the preparation of curd was the ultimate object of the trials, much useful information was obtained by detailed analysis of other materials, particularly the whey associated with curd. During the course of the trials, samples as required were taken to the Dairy Laboratory, Wallaceville, to be analysed. The analytical methods used are described in an appendix at the end of this paper.

Outline of Trials

The containers used for the *first* series were ten 50-gallon iron drums in five pairs labelled A and B, C and D, E and F, G and H, L and M, and one 80-gallon wooden cask, labelled W. Four of these, B, D, F and H were sunk to nearly their full depth into the ground and the remainder were left standing on the surface. These drums were unprotected except that for the first three months they were on the sheltered side of small army huts which were later removed. The sunken drums were covered over in the later stages to prevent farm animals getting at them. The drums were first filled and inoculated on the 10th October, 1945, and further additions of buttermilk were made on the dates given in Table I, which also summarizes the trial by giving the dates on which curd and whey samples were obtained, in each case before the removal of whey to make room for the addition of further buttermilk.

The first pair A and B, were used as uninoculated controls and to all the others varying proportions of ordinary cheese starter (*Streptococcus cremoris*) were added, while G and H, L and M, and W were also inoculated with *Lactobacillus bulgaricus*. Inoculations of 1-2 gal. were used for each drum, to ensure rapid souring. The controls soured and fermented in the same manner as the inoculated drums, but previous experience of other investigators showed that this might not always occur. The buttermilk used was obtained from the Featherston Dairy Factory, close to the farm on which the trials were carried out. As it was transported in a mobile tank also used for handling whey from the cheese vats, it would pick up a certain amount of lactic cheese starter,

and that probably explained the successful souring of the uninoculated controls. The progress of the initial souring was observed by titrating so as to give results expressed conventionally as " per cent. lactic acid ". The results at the end of the first forty-eight hours showed that souring in the sunken drums was taking place at a noticeably slower rate, for the figures were 0.45 to 0.51 per cent. as compared with figures of 0.60 to 0.73 per cent. for the rest. Lower underground temperatures would account for this. After three days the slower drums had caught up with the rest and all the figures were in the range 0.72 to 0.85.

Besides lactic acid, carbon dioxide was formed in considerable quantities, and as this gas rose to the surface it gradually took with it the curd, so that after a few days, there was on top of each drum a layer of curd several inches thick, buoyed up by the accumulated gas. Underneath was the whey which gradually drained out of the curd so that the latter became drier and firmer. In order to get the curd covered with whey it was broken up from time to time, until the curd gathered at the bottom, leaving the upper portion of each drum filled mainly with whey. In the early stages, the surface curd layer formed again after each addition of buttermilk, but later, when further buttermilk was added, the acidity of the mass was sufficient to precipitate the new curd immediately, so that it gathered upon that already accumulated at the bottom of each container before gas formation could occur. In the latter stages only odd lumps floated up and these sank on being broken to allow the gas to escape. Finally the drums were about four-fifths full of curd, covered by a few inches of whey. The product was a rather sloppy greyish-white mass which, when drained of surplus whey gave a soft granular curd.

TABLE I. FIRST SERIES—DATES OF OPERATIONS, 1945-46

Buttermilk.		Curd.		Whey.	
Added.	Analysed.	Broken.	Analysed.	Removed.	Analysed.
10/10	10/10				17/10
		27/10			27/10
5/11*	5/11	5/11	5/11	5/11	5/11
12/11			12/11	12/11	12/11
15/11	15/11	14/11		15/11	
19/11	19/11	18/11			
			28/11		28/11
6/12	6/12			5/12	5/12
					12/12
18/12					18/12
(W only)			29/12		29/12
			4/2		4/2
			4/3		4/3
					21/3
* E and F omitted			8/5		8/5

The whey samples of 17th and 27th October were obtained from under the curd by piercing it and thrusting a closed bottle down into the whey where the bottle was allowed to fill. After the curd had been broken on the 5th November the whey samples were taken by immersing a bottle in the surface layer. If much suspended curd entered the bottle the sample was allowed to stand so that the curd sank and portions for analysis were removed from the supernatant layer. From 4th March onwards the whey samples were obtained by filtering portions of wet curd

through a coarse filter paper for about three hours. In sampling curd from under the whey all surplus whey possible was drained from the sample while it was being bottled. Until the analyses were completed all samples were kept in a cold room at a temperature of 38° to 40°F.

The *second* series was begun on 28th November, 1945, using eight wooden casks each holding about 46 gallons, in four pairs, labelled O and P, Q and R, S and T, Y and Z, also a larger cask X, holding about 80 gallons, and a large wooden vat V of total capacity about 470 gallons. All of these were above the ground and right out in the open except V which was for about six weeks shaded by a small shed. Prior to filling with buttermilk they were all well scrubbed out and rinsed with a solution of chloride of lime. With the exception of O and P, which were controls, they were inoculated with mixed cheese starters *S. lactis* and *S. cremoris*, which were added to all the rest except X, to which *L. acidophilus* alone was added. To S and T and V some *L. bulgaricus* was added while to Y and Z some *L. acidophilus*. Inoculations of about 1 gal. were used except in V where a total of about 8 gal. was used. The vat V was at first only half-filled as it was inclined to leak, but later was about three-quarters filled. Some leakage continued from this vat and also from two or three of the casks.

The story of the remainder of the process is very much the same as in the first series. Warm sunny weather stimulated gas production so that the curd rose more quickly than in the first series, and the gas threatened to force the curd out of the top of the casks so it had to be broken up earlier than in the first series. Whey was removed and more buttermilk added, as indicated in Table II, the intervals being more uniformly spaced than in the first series. Before the curd was first broken up it had become slightly compacted in the narrow top of each cask so that its moisture content was lower. Later samples of curd from under the whey gave moisture figures similar to those from the first series. The curd itself had a rather whiter appearance than that of the first series, due to the absence of iron.

TABLE II. SECOND SERIES—DATES OF OPERATIONS, 1945-46

Buttermilk.		Curd.		Whey.	
Added	Analysed.	Broken.	Analysed.	Removed.	Analysed.
28/11	28/11				
6/12	6/12	5/12	5/12	5/12	5/12
12/12*	12/12	10/12		12/12	12/12
18/12	18/12	19/12†			
		20/12†		18/12	18/12
31/12*	31/12			29/12	29/12
10/1			9/1	9/1	9/1
			4/2		4/2
			4/3		4/3
					21/3
10/4 (V only)		† Where			17/4 (V only)
* Except P, R, T and Z		necessary	8/5		8/5

In discussing the results, reference is made to the effects of varying weather conditions. The drums and casks were left unprotected from weather changes with the object of carrying out the trials under conditions which would resemble as closely as possible the general conditions which would apply on most farms. Thus the information derived would be of more value to those intending to try to preserve curd by the methods studied.

TABLE III. BUTTERMILK ANALYSES

Date of Sample.	10/10/45*	5/11/45†	15/11/45§	19/11/45	28/11/45†	28/11/45§	6/12/45§	12/12/45	18/12/45	31/12/45
Spec. Grav. at 60°F.	1.0273	—	—	1.0252	1.0279	—	—	1.0268	1.0241	1.0248
Total Solids Per Cent.	7.52	8.25	6.13	7.13	7.62	7.53	7.62	7.23	6.73	6.92
Total Nitrogen Per Cent.	0.412	0.431	0.342	0.395	0.424	0.412	—	0.353	0.310	—
Total Protein Per Cent. (T.N. × 6.38)	2.63	2.75	2.18	2.52	2.71	2.63	—	2.25	1.98	—
$\frac{N}{T.S.} \times 100$	5.48	5.22	5.58	5.54	5.56	5.47	—	4.88	4.61	—
Lactose Per Cent.	3.67	3.86	1.18	1.87	2.98	3.20	2.76	3.22	3.07	3.09
Chloride as Cl^-ion Per Cent.	0.0694	0.0653	0.0651	0.0669	0.0693	0.0735	0.0746	0.0714	0.0694	0.0634

* Average of results for three samples. † Average of results for two samples. § Sample sour.

Results of Buttermilk Analyses

As the buttermilk was the starting material a fairly complete analysis of most of the samples was done to provide a basis for considering subsequent changes. The analyses were begun as soon as possible after sampling to avoid changes, but in some cases the sample became more or less sour so that certain values were affected, e.g., the total solids and lactose were both very low in the sample of 15/11/45. The results summarized in Table III indicate the composition of the buttermilk used over a period of three months.

(a) Specific Gravity variations were due to the fact that water was added to the cream for rinsing and other purposes during butter manufacture, so that the resulting buttermilk was diluted to a varying extent. Most of the samples had a specific gravity of about 1.027, but one sample with more water than usual had a specific gravity of 1.024 and total solids of 6.73 per cent.

(b) Total Solids figures were usually in the vicinity of 7.5 per cent., the variation being more or less parallel with the specific gravity and nitrogen content. Samples with lower lactometer readings due to added water gave lower values ; due to loss of lactose, sour samples were also lower in total solids. For lack of time, fat determinations were not done.

(c) Lactose figures ranged from 3.2 to 3.8 per cent. for samples analysed before souring except one apparently fresh sample which had the unusual value of 1.9 per cent. (with T.S. 7.1 per cent.).

(d) Total Nitrogen was determined to give an indication of the feeding value of the buttermilk, and since the resulting curd consists mainly of coagulated protein the figures can be used to indicate the degree of concentration of the protein during the process. The total nitrogen ranged from 0.35 to 0.42 per cent. with one or two exceptions. Using the accepted factor of 6.38 to convert these figures to protein, a range of 2.2 to 2.7 per cent. protein was obtained. On the earliest samples, protein partition determinations were done to get an indication of the distribution of the protein. On samples with a total nitrogen of 0.41 per cent. the results showed that of this, 0.385 per cent. was total protein (including nitrogen, 0.35 per cent. as casein nitrogen) and leaving only 0.025 per cent. as non-protein nitrogen. This gave a casein percentage of 2.2 and a soluble protein percentage of about 0.22, indicating a casein to soluble protein ratio of 10 to 1 as compared with about 8 to 1 in whole milk. The difference was due to the denaturation of the protein during flash-pasteurizing of the cream at 190° to 200°F.

As a check on apparent variations, a nitrogen to total solids ratio was derived. For most of the samples a value of about 5.5 was obtained indicating a fairly uniform composition for the buttermilk. Slightly lower ratios were obtained for later samples, but no reason for this could be suggested.

(e) Chloride determinations were done as a control to indicate subsequent changes. The results vary within the narrow range of 0.065 to 0.072 per cent. A weighted average of all the results gave a value of 0.0687 per cent. of chloride ion. By converting all subsequent whey results to this chloride basis the effects of both evaporation and rainwater dilution were eliminated, as is discussed later.

Most of these results are only indirectly related to the curd and whey results, except that they indicate the original composition of the material used to prepare the curd. The lactose is important on account of the part it plays as the source of lactic acid, etc. From the results can be obtained an estimation of the original feeding value of the buttermilk, and if desired theoretical figures for the yield of curd from a given amount of buttermilk. The composition of the buttermilk depends on the methods used at the dairy factory, and varies appreciably from day to day, but excessive dilution with water should be avoided when it is to be used for pig-feeding.

RESULTS OF WHEY ANALYSES

Associated with the curd was a considerable volume of whey which at first sight might have appeared to be a by-product of large bulk but of little significance. It was however important in several respects, and from its analysis was derived much very useful information about what was happening to the curd. The progress of souring and subsequent changes could be followed by acidity and pH determinations. During storage the lactose was gradually fermented and by lactose determinations the progress of fermentation, whether faster or slower, could be followed. The whey contained nitrogen in various forms about which analytical data might prove useful. Besides nitrogen compounds of lower molecular weight, there might also be soluble milk proteins or their derivatives which could not be precipitated like casein to form curd. Finely dispersed curd which had not become aggregated with the main bulk might also be determined as nitrogen when the whey was analysed soon after souring, or after the addition of more buttermilk. Later on if the curd decomposed during storage the nitrogen content of the whey should show an increase.

The total solids present in the whey included such variables as lactose and nitrogen compounds so that determinations of total solids could provide a general indication of the trend of changes which were occurring during storage. A minor constituent which could be quickly and easily determined was chloride and estimations of this ion proved very useful for control purposes.

The whey for the earlier analyses was obtained from the surplus which was being removed to enable more buttermilk to be added and was usually very gassy. Later on the curd almost filled the drums and casks, with only a small layer of whey on top and little or no gas. At that stage the whey samples were drained from curd taken deep down in the drums so as to be less subject to surface variations. As all the casks were out in the open, the composition of the whey was affected by climatic effects, which operated in three ways. Firstly, the drums let into the ground were kept cooler than those above ground, and secondly, especially in hot windy weather, the whey evaporated more readily from the surface. As the sunken drums were also somewhat sheltered from the wind, these two conditions together gave rise to the markedly lower chloride values yielded by samples from the sunken drums B, D, F and H of February 4th.

This is shown in the following figures which are per cent. of Cl ion :—

A, 0.103	C, 0.121	E, 0.114	G, 0.136	L, 0.135	W, 0.103
B, 0.094	D, 0.075	F, 0.081	H, 0.098	M, 0.124	

Thirdly, dilution occurred in wet weather. The extent of the variations produced by climatic effects was shown by two sets of samples taken at the same time from both series. In the first set which was chiefly surface whey, the chloride figures ranged from as low as 0.023 to 0.099 with an average of 0.0551 per cent. From deep curd samples taken at the same time the whey was drained and yielded chloride figures from 0.075 to 0.099, with an average of 0.0862 per cent.

All whey results recorded in Tables IV and V were converted to a value corresponding to the mean chloride concentration in the buttermilk used—0.0687 per cent. The chloride content of the initial whey was much the same (0.066 per cent.), but the average chloride figure from the buttermilk samples was preferred as the basic figure. By this means variations due to evaporation and dilution effects were largely eliminated, as is best shown in the graphs, Fig. 2. The uncorrected values for total solids of L on 12th December and 4th February were higher than they should have been, probably owing to evaporation by hot winds. In the case of S, slight dilution due to wet weather is shown in the values for 29th December. On the same date the values for V showed much more marked dilution due to rain water being accidentally blown into V from the roof of an army hut a few days before. On 10th April additional buttermilk was added to V to keep the curd covered and to replace loss due to leakage etc., a whey sample taken on 17th April gave a total solids value showing that the additional buttermilk had somewhat modified the whey composition. To supplement the graphs, in Tables IV and V are given the principal analytical results for whey for most of the containers. For brevity the remainder, which were similar, have been omitted.

As already mentioned acidity titrations were done to follow the initial souring of the buttermilk, but the results obtained from titrating the whey were rather variable, and latterly became very high, so that little significance could be attached to the figures. The pH of the whey was more constant. Soon after the buttermilk soured the values of the first series were 4.4, but a week or two later they dropped to 4.2, where they remained fairly consistently for most of the time. In the second series similar values were recorded, but after some months' storage, individual samples gave more variation, from 4.0 to 4.6.

First Series : (a) Lactose was used up by the initial bacterial fermentation to produce lactic acid, carbon-dioxide, etc. Determinations of lactose therefore gave an indication of the progress of fermentation, and after all the lactose had gone, showed when other changes might begin. The results have been expressed graphically (Fig. 1) by plotting the lactose concentration against the time in days, using lactose value for the first buttermilk as a starting point. As each further addition of buttermilk temporarily increased the lactose content, the lactose figures for the buttermilks have also been plotted as starting points, thus breaking the graphs into a series of smaller graphs joined by dotted lines. This eliminated those portions of the main graph which showed that lactose was being added, and gave a better indication of the rate of fermentation of the lactose. Points are shown for buttermilk additions on 12th and 15th November but as reliable lactose values for these were not available, lines from these points have not been drawn.

In Fig. 1 are graphs for A and B, and E and F ; similar graphs with minor variations were obtained for the other drums. In all cases the lactose was destroyed fairly rapidly, but the drop appeared irregular

TABLE IV. WHEY ANALYSES. FIRST SERIES

The figures represent Total Solids, Lactose and Total Nitrogen percentages.

Sample.	Sample dates.	17/10	27/10	5/11	12/11	28.11	5 12	12/12	18 12	29·12	4 2	4/3	21 3	8 5
A	Total Solids	4.87	4.49	4.36	4.42	3.52	3.06	3.31	2.93	2.64	2.90	2.71	2.76	2.75
	Lactose	2.45	1.25	0.94	1.60	0.23	0.07	0.35	0.09	0.00				
	Nitrogen	0.108					0.082	0.075		0.068	0.104	0.118		0.127
	*Formol							1.27	1.44		2.06	2.36	2.39	3.01
	*Ratio, Formol to Nitrogen							16.9			19.8	20.0		23.7
B	Total Solids	4.23	4.58	4.51	4.68	4.18	3.80	4.26	3.74	3.06	2.93	2.72	3.11	3.10
	Lactose	2.46	1.81	1.23	1.59	1.26	1.05	1.49	1.13	0.00				
	Nitrogen	0.075					0.068	0.073		0.085	0.084	0.113		0.137
	*Formol							1.01	1.18		1.47	1.95	2.40	2.69
	*Ratio, Formol to Nitrogen							13.8			17.5	17.3		19.6
E	Total Solids	4.71	4.57	4.42	3.98	2.94	2.61	2.86	2.70	2.21	2.36	2.34	1.81	1.75
	Lactose	2.74	2.04	1.45	0.15	0.00	0.00	0.17	0.00	0.00				
	Nitrogen	0.104					0.069	0.075		0.080	0.092	0.120		0.133
	*Formol							1.36	1.49		1.87	2.96	2.96	4.36
	*Ratio, Formol to Nitrogen							18.1			20.3	24.7		32.8
F	Total Solids	4.79	4.55	4.50	4.38	4.03	3.68	4.03	3.74	3.08	2.95	2.46	3.19	2.74
	Lactose	2.72	1.78	1.20	0.51	1.19	0.82	1.47	1.07	0.00				
	Nitrogen	0.107					0.071	0.069		0.083	0.089	0.092		0.147
	*Formol							0.97	1.12		1.69	1.83	2.30	3.69
	*Ratio, Formol to Nitrogen							14.1			19.0	19.9		25.1

Table IV. (Continued.)

L	Total Solids	4.64	4.73	4.33	4.69	3.01	2.59	3.73	3.41	2.74	2.62	2.61	2.89	2.80
	Lactose	2.79	2.03	1.82	2.00	0.37	0.00	1.53	1.06	0.00				
	Nitrogen	0.102					0.077	0.070		0.093	0.102	0.139		0.135
	*Formol							1.28	1.49		1.94	2.80	2.74	3.26
	*Ratio, Formol to Nitrogen							18.3			19.0	20.1		24.1
M	Total Solids	4.86	4.68	4.57	4.65	3.39	2.73	3.41	3.07	2.49	2.62	3.12	3.00	2.77
	Lactose	2.84	1.94	1.75	1.75	0.21	0.00	0.86	0.36	0.00				
	Nitrogen	0.102					0.074	0.075		0.079	0.090	0.120		0.119
	*Formol							1.14	1.41		1.68	2.50	2.34	2.73
	*Ratio, Formol to Nitrogen							15.2			18.7	20.8		22.9
W	Total Solids	4.69	4.80	5.16	4.58	3.54	2.98	3.99	3.75	2.99	2.83	2.90	3.44	3.20
	Lactose	2.83	2.13	2.32	1.63	0.21	0.18	1.84	1.44	0.12				
	Nitrogen	0.102					0.089	0.076		0.056	0.105	0.163		0.189
	*Formol							1.44	1.57		2.18	3.02	3.38	4.40
	*Ratio, Formol to Nitrogen							18.9			20.8	18.5		23.3

* Analytical methods for determining Formol values and Formol to Nitrogen ratio values are described in the Appendix.

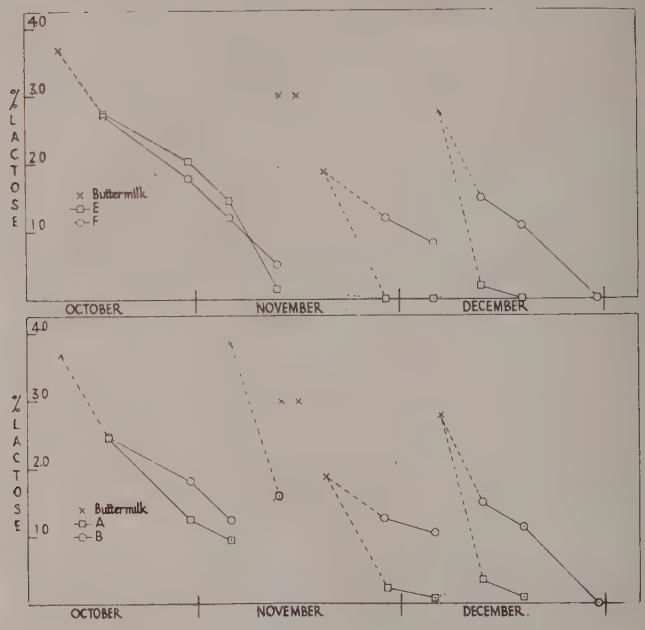

FIG. 1.—To show changes in lactose content of whey.

owing to the increase due to more buttermilk being added. Once addition of buttermilk ceased the lactose soon became completely used up.

In these graphs, a significant fact is that for A and E (above ground) the lactose fell off rapidly and further buttermilk did not maintain the lactose content for very long. In B and F the drop was slower and lactose was present in larger amounts for much longer after each addition of buttermilk. This was no doubt due to the lower temperature in the underground drums slowing down the rate of fermentation—an important point.

(b) Total solids at first ranged mostly from 4.5 to 4.9 with an average of 4.7 per cent. then gradually dropped as the lactose was used up, with slight rises after more buttermilk was added, (e.g., Fig. 2, graph L, points for 12th November and 12th December) until, with the loss of all the lactose, low values were reached. Except for slight irregular variations, values then remained fairly constant in the vicinity of 2.5 to 3.0 per cent. This suggests that very little curd was dissolving in the whey. In W, however, after the initial low value was reached there was a slight but distinct rise in total solids from 2.8 to 3.2 per cent. Similar observations were made in the second series and the explanation will be discussed later.

(c) Total nitrogen determinations could not be done on several early batches of samples and the picture is therefore incomplete. The initial values given by most of the first samples were close to 0.10 per cent., and these rather higher values were probably due to the presence of finely dispersed casein which had not become aggregated with the bulk of the curd. Later figures in December, before and after the last addition

of buttermilk, were lower, (about 0.07 to 0.08 per cent.). The values then increased only slightly to about 0.09 per cent. in February, then to about 0.12 per cent. in March and finally to about 0.14 per cent. on 8th May. In W a greater increase was noticed, as with the solids figure, and that again was similar to the second series.

To indicate the progress of curd breakdown and solution in the whey, "formol" titrations of the available amino-groups were done on all samples in the later stages. The results of these are shown in Table IV where figures represent ml. of 0.1 N. sodium hydroxide per 10 ml. of whey, and are adjusted to a fixed chloride content, Cl = 0.0687 per cent. The values obtained for samples taken after the addition of buttermilk had ceased, over a period of more than five months, rose from a range of about 1.0 to 1.4 ml. to a range of 2.9 to 4.4 ml. This distinct rise showed that breakdown to the curd to give soluble nitrogen compounds was taking place though quite slowly. In the case of W there was a more marked rise, parallel with the nitrogen and other values mentioned above. Most of the formol titrations for the sunken drums did not rise to quite the same extent as the remainder so that cooler temperatures apparently retarded decomposition slightly. To illustrate the increasing proportion of amino-nitrogen in the whey, the ratio, formol titration to total nitrogen, has been calculated and, with odd exceptions, most of the figures so obtained showed a gradual increase over the time considered.

(d) Chlorides were done as a control and their value in eliminating the effects of the weather has been shown. At first they remained fairly constant at about 0.066 per cent., but gradually rose to 0.08 to 0.12 per cent. (average 0.094).

Second Series: As the containers used were wooden casks above the ground together with a wooden vat, they did not get so hot in the sun as the iron drums, but some of them leaked a little.

(a) Chloride figures showed a rise similar to that observed in the first series, from 0.067 per cent. originally to 0.07 to 0.09 per cent. (average 0.081 per cent.) at the last. All the results in Table V, have been converted to a chloride concentration of 0.0687 per cent. and only the adjusted figures are discussed.

(b) Lactose results showed a gradual fall similar to that in those of the first series standing above the ground, but the additions of more buttermilk at frequent intervals checked the fall in values. In most cases the lactose was all fermented at the end of two months, twenty days after the addition of the last buttermilk.

(c) Total solids values were at first in the range 4.6 to 4.8 and fell gradually as the lactose was used up, while addition of buttermilk caused rises, e.g., values of 9th January for S and V shown in the graphs (Fig. 2). The V sample for that date was high in both total solids and nitrogen, due to a larger amount of buttermilk being added on 31st December. The lactose was fermenting slowly and the curd had not aggregated well owing to its gassy condition. When the lactose was practically all gone, values on 4th February ranged from 1.0 to 2.7 per cent., but during the next three months a gradual increase took place in all cases, so that the final range became 2.2 to 3.3 per cent. This is comparable with W of the first series, and is discussed later.

TABLE V. WHEY ANALYSES. SECOND SERIES

The figures represent Total Solids, Lactose and Total Nitrogen percentages.

Sample.	Sample dates.	5/12	12/12	18/12	29/12	9/1	4/2	4/3	21/3	8/5
O	Total Solids	4.68	3.72	3.37	2.88	3.11	2.58	2.90	2.93	3.16
	Lactose	2.67	1.36	0.84	0.20	0.21	0.08			
	Nitrogen	0.075	0.077		0.080	0.092	0.099	0.166		0.175
	*Formol						1.69	3.01	3.00	3.90
	*Ratio, Formol to Nitrogen						17.1	18.1		22.3
P	Total Solids	4.80	3.73	3.22	3.03	2.90	2.19	2.74	2.93	3.12
	Lactose	2.78	1.41	0.72	0.53	0.44	0.03			
	Nitrogen	0.076	0.073		0.074	0.076	0.077	0.159		0.182
	*Formol						1.56	2.88	2.90	3.58
	*Ratio, Formol to Nitrogen						20.2	18.1		19.7
S	Total Solids	4.77	3.81	3.39	2.91	3.21	2.38	2.70	2.81	3.19
	Lactose	2.74	1.41	1.04	0.55	0.66	0.09			
	Nitrogen	0.074	0.074		0.077	0.083	0.083	0.147		0.179
	*Formol						1.48	2.80	3.15	4.30
	*Ratio, Formol to Nitrogen						17.8	19.0		24.0
T	Total Solids	4.70	3.87	3.51	3.37	3.22	1.59	1.94	2.42	2.20
	Lactose	2.84	1.44	0.84	0.92	0.55	0.00			
	Nitrogen	0.074	0.074		0.071	0.075	0.077	0.142		0.153
	*Formol						1.52	2.69	3.44	4.50
	*Ratio, Formol to Nitrogen						19.7	19.0		29.4

Table V. (Continued.)

V	Total Solids	4.73	4.19	3.55	3.07	3.56	2.32	2.01	2.43	3.34
	Lactose	2.83	1.75	1.06	0.89	1.48	0.95			
	Nitrogen	0.078	0.075		0.068	0.092	0.071	0.110		0.208
	*Formol						1.44	2.23	2.74	4.60
	*Ratio, Formol to Nitrogen						20.3	20.3		22.1
Y	Total Solids	4.80	4.01	3.68	3.24	3.07	1.71	1.85	2.45	2.28
	Lactose	2.83	1.67	1.26	0.83	0.67				
	Nitrogen	0.073	0.700		0.069	0.073	0.080	0.135		0.202
	*Formol						1.04	2.70	3.42	5.45
	*Ratio, Formol to Nitrogen						13.0	20.0		27.0
Z	Total Solids	4.81	3.91	3.66	3.50	3.10	1.79	1.97	2.40	2.34
	Lactose	2.87	1.38	1.04	1.19	0.68				
	Nitrogen	0.074	0.073		0.074	0.071	0.084	0.140		0.166
	*Formol						1.74	3.08	3.10	5.20
	*Ratio, Formol to Nitrogen						20.7	22.0		31.3

* Analytical methods for determining Formol values and Formol to Nitrogen ratio values are described in the Appendix.

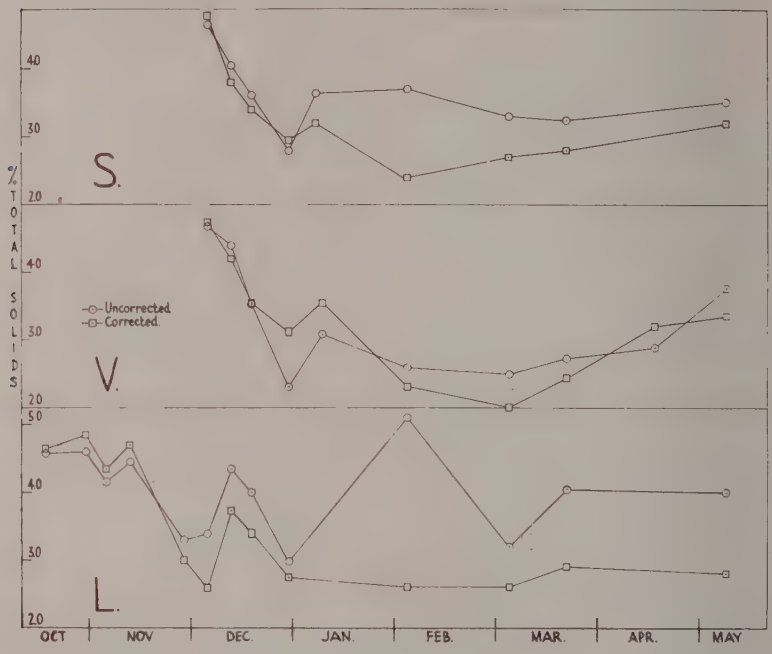

FIG. 2.—To show changes in total solids content of whey.

(d) Total nitrogen figures are available for most of the whey samples of the second series, so that they provide a more complete picture than in the first series. While buttermilk was being added at regular intervals most of the values remained fairly constantly in the range of 0.07 to 0.08 per cent. (which agreed with the values obtained in the first series before and after the last buttermilk was added). When no more buttermilk was being added and the lactose was used up, the values rose during the last twenty weeks to figures ranging from 0.15 to 0.20 per cent. for the last batch of samples. The formol titration figures obtained after the additions of buttermilk had ceased, showed a steady rise from rather less than 2.0 ml. to a range of 3.5 to 5.5 ml. These figures and the formol titration to total nitrogen ratios obtained from them, were similar to those of the first series but the rise was more marked.

In the first series, the solids and nitrogen values of cask W latterly rose more distinctly than those of the remainder, while a similar rise was quite noticeable in all of the second series towards the end of the storage period. This difference is illustrated in Fig. 2 in which graphs of the total solids values for L, S and V, both original and adjusted, have been plotted to show the effect of the conversion factor. In L, corrected, there is a fairly steady fall (apart from rises shown in samples of 11th November and 12th December due to buttermilk additions) with eventually a gradual flattening of the graph, whilst in S and V after an initial drop there is a steady rise. The following suggestions may explain this rise which occurred in the second series but not in the first. Except for W which was a wooden cask like all of the second series, the curd of the first series was stored in iron drums, and there were indications of a

relatively high iron content in the whey from these drums, e.g., the whey was a pale greenish-yellow colour, and on titrating it with alkali a blackish precipitate was obtained. Possibly the dissolved iron checked certain types of bacterial action ; also it may have helped to precipitate certain soluble protein material. It was noticed that samples of freshly filtered whey from the iron drums, on standing overnight, gave a gelatinous precipitate which settled to the bottom ; this did not occur in whey from the other samples. Thus in the iron drums there would be less soluble protein in the whey and the increase in nitrogen noted would be due to simpler degradation products, whereas the more marked increase of nitrogen and total solids in the whey from W and from the second series, would be due partly to some major portions of the casein molecule becoming dissolved. When the last samples were analysed, after a storage of 159 days, the corrected whey nitrogen figures for the second series had a range of 0.15 to 0.20 per cent., while in the first series after 208 days storage, W was 0.19 per cent., but the samples from the iron drums had a lower and narrower range of 0.12 to 0.15 per cent. These figures are more significant than the trend shown by the total solids figures.

Effect of Variations

The results of the whey analyses show clearly how certain variations affected the process.

(a) *The use of starter*, i.e., of different types of lactic-acid-producing bacteria, did not appear to vary the process appreciably, but one or two points are worth commenting upon. The drums G and H, L and M, and the cask W were inoculated with *L. bulgaricus* in addition to cheese starter. As compared with G the lactose fermentation in H, sunk underground, at first took place more slowly (as it did in the other sunken drums), but after about a month the lactose values for H became lower than for G, indicating that it was being more quickly used up. This was accompanied by slightly lower total solids and nitrogen values in H, and this tendency persisted till the end of the storage period. Neither L nor M were sunk, but the *bulgaricus* inoculation for M was much greater than for L. In M, after about three weeks the lactose was persistently lower than in L. A few weeks after the last addition of buttermilk the nitrogen values for M were lower than for L, and this difference persisted to the end of the storage period. Apart from E to which no buttermilk had been added on 5th November, the only drums in which the lactose content was zero on 5th December were L and M. Possibly this quicker fermentation in L and M may have been due to the *bulgaricus* culture, and the much heavier inoculation of M may have accounted for its lactose being used up more quickly than that of L. The results in W were different from all the remaining drums, partly on account of temperature effects, and partly owing to the absence of iron salts. Whether the *bulgaricus* culture also contributed to the differences is doubtful. In the second series however, the inoculation of S and T, and V with *bulgaricus* did not produce any similar effects, so that the use of *bulgaricus* was probably not the real reason for the effects discussed above in the first series. The use of *L. acidophilus* for X, Y and Z in the second series apparently did not modify the process. Both cultures of lactobacilli which were used grow best at warm temperatures (30 to 37°c.) and on that account may have been less suitable than lactic streptococci. If the controls in both series had

not soured readily due to adventitious inoculation derived from cheese whey, they might have shown more clearly the effect of lack of starter addition.

(b) *Temperature* variation produced appreciable differences in several cases. This was noticed early in the slower souring of the buttermilk in the sunken drums of the first series ; also the curd in these drums was not so firm at the end of the first week, as a result of slower gas formation. Thus the lactose in these drums lasted longer, as shown in Table IV, where the values for B and F were respectively higher than for A and E. With higher lactose values, higher total solids values were also obtained. This effect of lower temperature was noticeable in H as compared with G for the first month. Later results for this pair were, however, slightly anomalous due to some undisclosed reason.

On sunny days the cask W was cooler than the iron drums so that whey samples from W gave higher lactose and total solids values than the drums above the ground. Again in the second series the vat V was at first shaded by an army hut, and later a screen was placed along its sunny side to check the warping of the wood which was giving rise to leakage. As a result the temperature of the large bulk in the vat did not rise as much as in the casks, so that after 5th December whey from the vat tended to be higher in lactose than from the casks, with a similar though less marked tendency in total solids content. A combination of low temperatures with insufficient milk-souring bacteria at the beginning of the process might however enable undesirable types of bacteria to predominate, and spoil the process.

(c) *Frequency of buttermilk addition*, was observed to produce marked differences. No buttermilk was added to E and F on 5th November, with the result that whey from this pair on 12th November had a lower lactose content than all the rest, while the total solids and lactose for E continued to be lower than all the rest. However, F had a higher total solids and lactose than all except B ; this would be due to the fact that larger volumes of whey were removed from E and F on 12th November, and so larger volumes of buttermilk added to replace it, as compared with the remaining drums. The cooler temperature of F underground checked fermentation of the lactose which by contrast took place in E very rapidly. Similar contrasts were noticeable in the total solids and lactose contents of whey samples from E and F on the 5th and 12th November when F continued to have higher lactose and total solids values.

In the *second* series, to observe the effect of longer time between buttermilk additions, none was added to P, R, T and Z on two occasions, 12th and 31st December. In these casks the lactose values of P, T and Z were slightly lower than the corresponding cask of each pair when the whey was analysed a week later (18th December), but samples from the casks P, R, T and Z taken for analysis on 29th gave distinctly higher values for both total solids and lactose as compared respectively with O, Q, S and Y. This was apparently due to the larger bulk of buttermilk which could be added to these casks on the 18th, with the result that the lactose concentration in the whey was raised higher, and so took longer to be fermented. Along with this there was a tendency noticed in the pairs of whey samples of 29th for those with higher lactose to have slightly lower nitrogen (except Z). That difference probably indicated more complete precipitation of the curd. After the final addition of buttermilk on 10th January, further whey samples were

not analysed soon enough to enable the repetition to be noted of this effect on the lactose figures, but on 4th February and 4th March in the case of P, R and T, both total solids and nitrogen figures were distinctly lower than those respectively of O, Q and S. The corresponding values for Z were only slightly higher than for Y. These results suggest that additions of buttermilk should be made at longer rather than shorter intervals, in order to keep the curd as long as possible in whey containing lactose, and to enable the curd to separate more completely from the whey.

Results of Curd Analyses

Samples of the curd were analysed at intervals chiefly for total solids and total nitrogen. These determinations were done in one or two cases directly on the wet curd ; in other cases the surplus whey was first drained off, sometimes by pouring away the supernatant liquid, but latterly by placing the curd in a large filter paper (fluted folding) in a funnel. The moisture content, and its reciprocal, the total solids, therefore varied somewhat from batch to batch of samples, and as chloride determinations were not done, adjustments to the results were not possible.

(a) In the *first* series, samples taken on 5/11/45, a few days after the curd was first broken up, yielded total solids values ranging from 12.5 to 13.8 per cent. Well-drained samples taken a week later, 12/11/45, yielded values of about 16 to 18 per cent. Six weeks later, 29/12/45, samples from which the whey had been merely poured off were mostly in the range of 9 to 10 per cent. The last batch of samples, 8/5/46, of the undrained semi-liquid curd had values ranging from 10.0 to 11.5, average 11.0 per cent. When the curd was well drained the total solids values ranged from 13 to 18 per cent., the average for the samples of 8/5/46 being 16.0 per cent. Total nitrogen values on drained curd ranged from 1.2 to 1.8 per cent., so that using the factor 6.38, protein values ranged from 7.6 to 11.5 per cent. None of these results showed any definite trends, but on calculating the nitrogen to total solids ratio as a percentage, figures in the vicinity of 10 were usually obtained. This showed that, despite some slight variations, the protein content of the curd itself was remarkably constant throughout the period of storage.

(b) In the *second* series the total solids values of the curd ranged from about 9 to 12 per cent., and in the well-drained curd from 14 to 16 per cent. The undrained curd samples of 8/5/46 had total solids values ranging from 9.2 to 12.4 per cent. (average 11.0), while the same samples well-drained gave values from 14.7 to 16.0 per cent. (average 15.4). Total nitrogen values obtained on various occasions ranged from 0.9 to 1.1 per cent. for the undrained curd and from 1.4 to 1.8 for the filtered curd. These figures were similar to those of the first series and the same total nitrogen to total solids ratio figures in the vicinity of 10 were obtained with rather less variation. The ratio figures were practically the same for both drained and undrained curd. These results therefore, indicated little change in the composition of the curd and served as a check on the preservation process and also as an indication of the feeding value of the curd, based on its protein content.

In the *second* series, before the curd was first broken the gas underneath pressed the curd into the narrowing opening of each of the casks, and this compacting effect, together with the warm sun and wind, produced a much drier curd. Samples taken from three casks before breaking up the curd to release the gas gave total solids figures around

21 per cent., while one was as high as 29 per cent., but a similar sample from the large vat was just under 17 per cent. These results make clear the saving in storage space which might be achieved if instead of sinking the curd to store it under the whey, it were drained of surplus whey and stored in suitable air-tight containers.

Certain chemical properties of the curd may be deduced from chloride determinations which were done upon only one batch of samples, including both the first and second series. The curd for the analyses had been drained by filtering and the corresponding whey samples were also analysed. At first sight no relation could be traced between the chloride content of the curd and that of the corresponding whey. But on expressing the chloride as a percentage of the water present in each case a fairly definite correlation appeared. This was made evident by calculating the ratio of the chloride in the curd water to the chloride in the whey water. Out of samples from 21 different containers, this ratio in the case of no less than 12 lay between 1.16 and 1.19, with an average of 1.18. For the remaining 9 containers the ratio in 2 cases was below 1.0, while in the 7 other cases it ranged from 1.08 to 1.26 with an average of 1.19. The fact that the chloride ion concentration in the water associated with the curd was higher than it wasin the whey water was probably due to a Donnan membrane effect. If this were the case the ratio might be altered by changes in the physico-chemical state of the curd, particularly its degree of hydration, and this in turn might alter as breakdown from larger to smaller molecules took place. Unfortunately chloride determinations were not done regularly on the curd so that this possibility could not be further studied.

In the undrained curd, which in practice, would be the product used for feeding, about 89 per cent. was water when the last samples were taken, and of the 11 per cent. total solids, fully 6 per cent. was protein. The remaining 4 per cent. consisted of ash, salts of such organic acids as lactic acid, etc., and a small amount of fat, usually less than 1 per cent.

From the results of the chemical analyses for total solids and for nitrogen some idea can be obtained of the concentration effected by the process. The original buttermilk had a nitrogen content of about 0.4 per cent. Results obtained from undrained curd of the first series sampled on 29/12/45, gave an average total solids value of 9.4 and this curd was found to have its nitrogen about 10.2 per cent. of its total solids. Thus the nitrogen content of the curd itself would be about 0.96 per cent. The concentration figure is therefore 0.96/0.4, i.e., 2.4. Similar calculations from results obtained towards the end of the storage period gave a rather higher figure, which approached figures obtained likewise from the second series, 1.12/0.4, i.e., 2.8.

Starting from the original buttermilk total solids figure of about 7.5 per cent., this becomes only 11 per cent. in the final undrained curd ; but if allowance is made for the loss of lactose, about 3.4 per cent., the original buttermilk solids drop to 4.1 (i.e., 7.5 minus 3.4). Thus the concentration figure is obtained by dividing 11 by 4.1 giving the result, 2.7, which is only a little lower than the figure derived from the nitrogen analyses.

However according to conditions some variations may occur, so the concentration or reduction in volume effected by the process can be reckoned to be rather less than three times. After long storage, evaporation may cause the concentration to approach or even exceed three times. This effect was made clear during the Featherston trials by chloride determinations on the whey, which rose from below 0.07 to about 0.09, with odd samples above 0.1 per cent.

General Discussion

During these trials curd was prepared and stored in good condition in various containers for periods of 6 to 8 months. By chemical analysis of the buttermilk, whey, and curd, information was obtained about the changes which occurred during the storage process. On account of other work in hand it proved impossible to do as much analytical work as might have been useful, nor was it possible to work up the results and study them in detail during the course of the trials. Consequently some factors which might profitably have been studied by fuller analysis were overlooked. During the progress of the trials notes were made of various details such as the amount of curd floating, the variation in gas condition of the whey, differences in colour and cloudiness of the whey during the early stages while buttermilk was still being added. The possible correlation of such points with later developments did not eventuate. In planning the trials an important consideration was to vary the conditions as much as possible to see if some were preferable to others. In retrospect it appears that more chemical information might have been obtained if fewer containers had been used so that more frequent sampling for analysis could have been undertaken. This would have provided a more complete chemical picture of the progress of the changes.

On buttermilk samples, lactometer readings were done usually the same day as they were taken, but if it had been possible to do also total solids, lactose, etc., the same day instead of the following day that would have enabled the amount of added water to be determined fairly accurately, and thus differences in the composition of the buttermilk on different occasions might have been explained. Fat determinations on buttermilk would have enabled Richmond's formula (2) for total solids, and Udy's (3) for added water to have been applied. The weighted average figure for chlorides is more accurate for the first series than for the second series in which some of the earlier samples of buttermilk were not used. However if the basic chloride figure were varied slightly that would not affect appreciably the general trend of the results.

Throughout the trials the whey samples were very fully analysed, but more frequent total nitrogen and formol determinations in the early stages might have been useful. In addition, total protein nitrogen as distinct from total nitrogen determinations would have helped to show how much of the nitrogen was due to casein which had not aggregated upon the curd, especially in the earlier stages while buttermilk was still being added. Total protein determinations would also have been useful to indicate the trend of casein decomposition and to supplement information yielded by formol titrations. In some cases slight differences were noticeable in the composition of the whey which was separated by pouring from the curd and that obtained by filtration but it was not possible to investigate these differences, which were chiefly in the nitrogen content.

So long as the mixture of the curd and whey remained at a fairly low pH, as determined on the whey, the need for detailed analysis of the curd seemed to be not quite so pressing. The curd analyses were therefore confined chiefly to total solids and nitrogen determinations, and these served to indicate the constancy of composition of the curd, as well as its feeding value. As already pointed out chloride determinations on the curd might have provided some useful data to indicate changes in its physico-chemical condition. To provide fuller information about

the feeding value of the stored product, fuller analysis would have been useful especially on account of the gap between total solids and total protein content. A few determinations showed that this gap was partly filled by the presence of fat (about 1 per cent.), ash (about 1 per cent.), and lactic and other organic acids. A series of determinations would have helped to provide more data about these constituents, which were however secondary to the main feeding value of curd derived from its protein content.

Provided a sufficient inoculation of lactic-acid-producing bacteria is present originally, a high acidity, (pH 4.2 to 4.4), can be obtained fairly rapidly so as to precipitate and coagulate the casein into curd. Apart from the formation of the curd, the souring also plays an important part in the storage because when the material is sufficiently acid the multiplication of a variety of bacteria is checked, and putrefaction cannot so readily occur.

It is a well-established principle that in the presence of a fermentable carbohydrate, proteolytic bacteria use this carbohydrate in preference to attacking protein material (4), (5). In the present investigations this principle appeared to apply for there was little decomposition of the curd while lactose was present, and after the lactose was all used up, the curd dissolved very slowly, as shown by determination of both total nitrogen and formol values in the whey. These results showed that it was desirable to maintain the lactose content as long as possible and this could be done in two ways ; firstly by spacing out the additions of buttermilk at longer intervals (10 to 15 days) rather than shorter (5 to 10 days); secondly the slower fermentation of the lactose in the sunken drums showed that a lower storage temperature was preferable. After the lactose was used up there was practically no tendency for the curd to rise to the surface of the whey, and at that stage another important factor operated in conjunction with the acidity, namely the exclusion of air which was effected by keeping the curd covered with whey. Just as in making ensilage, it was important to exclude air so as to check the multiplication of various types of bacteria which were capable of growing and decomposing or putrefying the curd.

The acid conditions in the curd would no doubt favour the growth of very large numbers of harmless lactobacilli (e.g., *Streptobacterium casei*) which are common in cheese. Apart from these the principal types of organisms likely to grow are yeast and moulds. The former are less important than the latter which usually produce appreciable amounts of ammonia and similar substances which are capable of neutralizing the acidity. If this should occur in a confined spot where the effect is localized the pH may rise and enable other bacteria present to develop so that decomposition may soon proceed rapidly ; but any mould spores which chance to be blown on to the surface layer of whey will sooner or later become submerged due to air currents so that mould growth is thereby checked. This is one advantage of not having these containers provided with covers. Towards the end of the trials when covers were required on the sunken drums to prevent the access of farm animals, a film of mould growth developed here and there on the surface of the whey.

If the storage of the curd were attempted by draining the whey from it and placing it in a cask or drum, special care would need to be taken to use an air-tight container and to press the curd well down so as to exclude air. A tight fitting lid would also be necessary to limit the access of air to the top as much as possible, with the object of checking the growth of mould and proteolytic bacteria.

The results showed that the preservation of curd in many respects followed the traditional process of cheese-making. The final product was of course very different from cheese made in a factory where the curd was removed from the whey, drained and pressed but the underlying bacteriological and chemical changes were essentially the same. In both cases acidity was developed to produce the curd and check the growth of undesirable bacteria, which were also suppressed by the exclusion of air.

Towards the end of the storage period the rising nitrogen content of the whey revealed a slight tendency for the curd to decompose. This would normally be checked with the advent of cooler weather, and longer storage would not often be needed. Although some variations were noticeable in the results of the whey analyses, especially during the earlier stages, after six to eight months' storage no significant differences were noticeable in the properties of the curd in the different containers. From this it may be deduced that considerable latitude is permissable in the preparation. Nevertheless, to secure the maximum efficiency of storage, due attention should should be given to certain points which have already been emphasized, e.g., liberal inoculation with an active cheese starter culture to initiate rapid souring ; avoidance of warm temperatures by shading the containers from the sun, and addition of buttermilk or skim milk after longer rather than shorter intervals. These and various other practical points (including food values and economic aspects) have been described in detail in an illustrated article (1).

These investigations were sponsored by the National Pig Industry Council, which provided a small grant from its funds towards the expenses. Much valuable assistance with many practical details was rendered by Mr. H. M. Peirson, Superintendent of the Pig Industry. Besides other assistance which has been acknowledged in the Bulletin (1), mention should be made here of help given by Mrs. D. R. Perrin with some of the chemical analyses, and by Mr. A. L. Bryant in preparing the graphs.

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APPENDIX OF ANALYTICAL METHODS

The analytical methods which have been used are described separately in this Appendix so as to avoid confusion with the principal subject matter.

Specific Gravity : This determination was carried out on all buttermilk samples, except those which had became sour, by adjusting the temperature to $60 \pm \frac{1}{2}$°F. and using a finely graduated lactometer.

Acidity : (a) *Titration.* To indicate the progress of souring 9 ml. of buttermilk or whey was titrated with 0.1N. sodium hydroxide using 1 ml. of 1 per cent. phenolphthalein per sample, and the results were recorded conventionally as "per cent. lactic acid". Satisfactory results were obtained in the early stages of souring, but with very sour samples from the casks or drums, the presence of curd particles of varying size gave unreliable results. Clear whey could be easily titrated but when more or less finely divided curd was dispersed in the whey, the results were erratic.

(b) *pH.* To find the pH of whey samples, 0.5 ml. of 0.04 per cent. bromo-cresol-green indicator was added to 10 ml. portions and the colour matched in a Lovibond comparator.

TOTAL SOLIDS: Into previously dried porcelain dishes about 3 to 5 g. of curd or 10 g. of buttermilk (pipetted) were quickly weighed. Light aluminium dishes were preferred for 10 g. whey samples (also pipetted). The dishes were heated for at least three hours in a steam oven, then cooled and weighed, followed by two heatings of at least one hour each in the oven, with subsequent weighings. Owing to the acid condition of the material further heating gave slight further loss in weight due to volatile fatty acids, etc., being driven off. Occasional trials of longer heating were made, but the effect on the results of further slight losses in weight were hardly significant. As the dry material was very hygroscopic, speed was necessary with the final weighings, and too many dishes could not be placed in one desiccator. The results have been expressed as grams of dry matter per 100 g. of sample.

Determinations were carried out as soon as possible after collecting the sample, lest storage, particularly for curds, should lead to the production of volatile products, thereby lowering the total solids value. When weighing curd samples thorough mixing was necessary to ensure agreement between the duplicates.

CHLORIDES: According to Volhard's method, to 25 ml. of whey or buttermilk in a 300 ml. conical flask, were added 10 ml. of accurately standardized tenth-normal silver nitrate, followed by 10 ml. of concentrated nitric acid (commercial acid was found satisfactory if chloride free). The flasks were boiled gently on a hot plate until the liquid cleared. To determine the unprecipitated silver, the resultant solution, after diluting to fully 100 ml. was titrated with approximately tenth-normal potassium thiocyanate solution, using iron-alum as indicator. For each batch of samples, blanks were done in order to standardize the potassium thiocyanate and as a check on the purity of the nitric acid. The results were expressed as grams of chloride (Cl^- ion) per 100 g. of sample.

Later, when insufficient whey was available, determinations were done on the mixture resulting from the formol titration, containing 10 ml. of whey. In this case 5 ml. tenth-normal silver nitrate and 5 ml. of nitric acid were added. To avoid excessive frothing due to the formalin, these samples were warmed gently in a water-bath. The presence of the formalin did not appear to affect the results obtained as compared with those given by the usual method with 25 ml. of whey. For dealing with smaller amounts of whey, a finely graduated burette and more dilute standard silver nitrate and thiocyanate solutions were preferable.

On some of the later batches of curd a chloride determination was done on 10 g. of curd using 5 ml. of tenth-normal silver nitrate and 20 ml. of nitric acid. Rather longer heating was required to complete the digestion, after which the solution was diluted and titrated in the usual way.

LACTOSE: Determinations were done on buttermilks and on whey samples obtained at intervals until all the lactose had been fermented. For this purpose the method of Lane and Eynon (1) was used as modified by McDowell (2). This method depends upon the treatment of a precise amount of Fehling's solution with a portion of the milk or whey sample and subsequent titration of the unreduced copper with standard lactose solution. The quantity of lactose solution equivalent to the Fehling's solution may be determined by a blank titration. Hence may be obtained the amount of standard lactose solution equivalent to the lactose in the milk or whey, and therefore the percentage of lactose in the sample. There are two steps to the determination; first, an approximate titration to give a preliminary indication and secondly an accurate titration to give the precise result. Fat and protein need not be removed as in other methods provided the sample is sufficiently diluted with distilled water. Four solutions are required, and equal volumes of numbers 1 and 2 are combined to form Fehling's solution, taking care to pipette No. 1 accurately.

1. Copper Sulphate:—Dissolve 34.639 g. of Analar $CuSO_4.5\ H_2O$ in 500 ml. of distilled water. This solution is the standard and must be accurately made up in a standard flask.

2. Alkaline Tartrate:—Dissolve 173 g. of pure sodium potassium tartrate, and 51.6 g. of NaOH in 500 ml. distilled water. The equivalent amount of bi-potassium tartrate may be used. It is convenient to use approximate 50 per cent. NaOH solution as this is carbonate-free and its strength may be estimated by titrating.

3. Lactose, 0.5 per cent:—Dissolve 2.50 g. of lactose monohydrate in 500 ml. of water in a standard flask. This standard solution is best made up as required for it tends to grow moulds.

4. Methylene Blue, 1 per cent.:—Dissolve 0.1 g. in 10 ml. water, by warming on a water bath. It is preferable for this solution to be fairly fresh.

With an accurate pipette, 5 ml. of solution 1 were measured into a 250 or 300 ml. conical flask and then 5 ml. of solution 2 were added by pipette, or burette (but not glass tap). To the mixture, 2 ml. of the sample were accurately pipetted (less or

more according to the lactose content). After adding 10 ml. of distilled water, the mixture was heated quickly till it boiled. After boiling for two minutes, if reduction was fairly complete, 2 drops of methylene blue were added. If however, the colour indicated that reduction was incomplete, 2 to 3 ml. of lactose solution were added, followed by 2 drops of methylene blue. After 30 seconds more boiling, the flask on stand and burner were moved to underneath the burette, whence lactose solution was gradually run in, with 10 seconds boiling between each addition, until the methylene blue decolourized and the liquid became bright red.

As the methylene blue is an internal indicator, the colour change is sudden, from deep purple to bright brick red and is usually completed with one drop of lactose solution. In all, the solution should not be boiling for more than five minutes. With experience, the analyst could tell approximately how much reduction had taken place, by the appearance of the solution when it was first boiled. The flask should not be heated directly under the burette for longer than is absolutely necessary, especially in the final titration.

For the accurate final titration, the same quantities of solutions and whey or buttermilk were pipetted out, but before boiling, the standard lactose solution was run in to within 0.5 ml. of the amount already determined.

The mixture was boiled (away from the burette) for two minutes, indicator added, and then the remaining lactose solution was added drop by drop while being boiled under the burette, until the end point was reached.

The results were calculated as follows :—If A were the volume (ml.) of 0.5 per cent. lactose required for 10 ml. of Fehling's solution and B the volume required to complete reduction after adding X ml. of sample, then 1 ml. of sample equalled $\frac{A - B}{X}$ ml. of 0.5 per cent. lactose solution. Therefore the lactose in 100 ml. of sample was $\frac{A - B}{X} \times 0.5$. As the standard solutions were all made up from lactose monohydrate the results were expressed as grams of lactose monohydrate per 100 ml.

Nitrogen ; (a) For *Total Nitrogen* the usual Kjeldahl method was at first used. In this 3 to 5 g. of well-mixed curd were digested with 25 ml. of concentrated sulphuric acid and 5 g. of anhydrous sodium sulphate, using 1 ml. of 5 per cent. copper sulphate solution as catalyst. To ensure complete conversion to ammonia, care was taken to continue heating for fully an hour after the liquid cleared. After diluting sufficiently the clear digest was made alkaline with about 60 ml. of approximately 50 per cent. sodium hydroxide solution, and the ammonia distilled into 0.1 N. sulphuric acid. The excess acid was titrated with 0.1N. caustic soda, using methyl red -methylene blue indicator. Blank determinations were done with each batch, and the results expressed as grams of nitrogen per 100 g. of curd.

Total nitrogen was done on the earliest batch of whey samples by the above macro-method using 10 ml. of whey, but, as too much time was needed to deal with large numbers of samples, a micro-method was used. The method adopted employed a slightly modified digestion mixture and the Parnas-Wagner Kjeldahl steam distillation outfit similar to that described by Clark (3). Either 1 or 2 ml. of whey was digested with 1.5 ml. of concentrated sulphuric acid and 0.5 g. of sodium sulphate, with 40 mg. of mercuric oxide as a catalyst. The clear digest was diluted, transferred to the distillation outfit, and made alkaline with a solution containing 40 per cent. sodium hydroxide and 5 per cent. sodium thiosulphate. The ammonia was then distilled into 2 ml. of 4 per cent. boric acid solution and the solution titrated with 0.02 N. hydrochloric acid using methyl red—methylene blue indicator. The acid was diluted as required, from 0.1 N. hydrochloric, which was checked by the usual silver nitrate method. The results were expressed as grams of nitrogen per 100 g. of whey.

(b) *Protein Nitrogen.* In order to get an indication of the amount of protein which would be available as curd, the first samples of buttermilk were analysed for casein and total protein according to the method of Moir (4). Briefly the method is as follows :—The casein was precipitated from 10 ml. of buttermilk diluted with water, by the addition of 1.5 ml. of 10 per cent. acetic acid followed by 4.5 ml. of 0.25 N. sodium acetate ; after filtering and washing, the nitrogen content of the precipitate was determined in the usual manner. The total protein was similarly precipitated from 10 ml. of buttermilk with 20 ml. of 10 per cent. trichloracetic acid, and the mixture was warmed to 50°c. for a few minutes before filtering. There was insufficient time to carry out protein partitions on any of the later buttermilk samples nor upon the whey samples.

(c) *Amino-Nitrogen.* To indicate the extent of protein decomposition, Sorensen's "Formol" method was applied to 10 ml. portions of the whey. After titrating with 0.1 N. sodium hydroxide to the first definite shade of pink (with 1 ml. of 1 per cent.

phenolphthalein as indicator), 2 ml. of approximately 33 per cent. "water white" formalin were added and the solution re-titrated to the same shade of pink. From the result was subtracted a blank done on 2 ml. of the formalin diluted to the same extent with distilled water. The first titration (without formalin) gave the acidity of the whey, but these values were somewhat erratic.

The so-called formol figures might have been converted to the equivalent percentage of amino-nitrogen by using a suitable factor, but in the present work it sufficed to use formol titration to total nitrogen ratio. The figures so obtained were quite arbitrary but indicated the extent to which the total soluble nitrogen was becoming decomposed.

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ADDENDUM

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Since the foregoing was written we have had occasion to examine samples of curd which had not been successfully stored. On a farm in North Auckland 12 forty-four gallon drums were used to store curd prepared from skim milk. Seven of these were successful, but the other five began to ferment and putrefy after froth from skim milk had been added to them. In the following table are shown the most important of the analytical results. The wet curd from the bottom of the containers was drained by filtering, so that the curd portion and the whey portion could be analysed separately. Sample A was from a drum showing considerable putrefaction, sample B was moderately affected, while sample C was from a drum which appeared to be normal. For the purpose of comparison the results have been adjusted to the average chloride content (.081 per cent.).

	A	B	C
pH of Whey	5.5	4.25	4.0
Acidity Titration (ml. 0.1 N. NaOH for 10 ml. Whey)	7.2	25.2	33.0
Whey Nitrogen (g. N per 100 g. Whey) ...	0.584	0.407	0.382
Formol Titration (ml. 0.1 N. NaOH for 10 ml. Whey)	21.0	9.4	6.04
Formol to Nitrogen Ratio, Whey	36.0	23.1	15.8
Percentage of Total Nitrogen in the Whey ...	30.0	21.5	16.9
Curd Brine to Whey Brine, Ratio	1.08	1.25	1.31
Curd Total Solids	18.1	15.9	15.7

The results in the table show a distinct difference and graduation from A to C. The values obtained from the ratios of curd brine to whey brine confirm the rather scanty evidence about this point which was discussed in the section on curd analyses. Decomposition of the curd reduces the amount of chloride which can be associated with it. The use of buttermilk for the Featherston trials may account for the ratio there being about 1.2 as compared with 1.3 given by curd from drum C, prepared from skim milk.

The total solids of the whey varied from 5.1 to 5.7 per cent. The nitrogen figure for the curd was between 1.73 and 1.89 per cent. while the percentage of nitrogen in the total solids of the curd was 9.5 in sample A, and in the vicinity of 11.5 for the other samples. Sample A was grey in colour while the others were whitish. The dark colour was probably due to the presence of ferrous sulphide formed from the iron dissolved from the drums and hydrogen sulphide from the breakdown of the protein. A positive test for sulphide was obtained from sample A, but not from the others.

The reason for the failure of A and B is as follows:—As the foam would resist attempts to mix it with the rest of the contents of the drum, the required acidity would not be quickly developed. The lack of acidity, together with the plentiful supply of air in the foam, would permit large numbers of different types of bacteria to develop and attack the protein. In addition, when the putrefactive bacteria became sufficiently well established they would then produce less acid conditions in the rest of the drum and so allow the putrefactive process to continue throughout the drum. This has obviously happened in sample A, and to a much less extent in sample B.

THE EFFECT OF SHEEP DROPPINGS ON YIELD, BOTANICAL COMPOSITION, AND CHEMICAL COMPOSITION OF PASTURE

II. RESULTS FOR THE YEARS 1942-1944 AND FINAL SUMMARY OF THE TRIAL

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(Continued from Volume XXIV, No. 1A, page 61A)

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Summary

Final results of a trial at Palmerston North to measure the effects of sheep dung and urine on pasture growth and composition are presented. Preliminary data were given in a previous paper and this report covers the final three years of the trial.

Grazing without return of dung or urine resulted in an average production of 10,000 lb. of dry matter per acre per annum. This was largely the result of sustained growth of the clovers which were adequately supplied with added phosphate and lime, but the growth of associated grasses was quite good.

Return of urine resulted in an increase in total dry matter production to the extent of 15 per cent. over no return, with a much higher proportion of grass in the sward.

Return of dung gave a similar (18 per cent.) increase in total dry matter production. There was a progressive increase in proportion of grass in the sward following the high preponderance of clovers in the early stages of the trial.

Return of both dung and urine gave an increase of 33 per cent. over the period. The grass dominance which developed in the early stages of the trial increased during the final two years.

Chemical compositions of herbage, dung and urine are presented together with balances for nitrogen, potassium, phosphorus and calcium in feed and excrement. The balances show reasonable agreement except in the case of nitrogen. The possible sources of error are discussed.

Introduction

This paper presents the final results of the trial previously described in a preliminary report by two of the present authors (1).

In that paper the objects, layout, and measurement techniques were fully detailed, the literature was discussed, and the results of the first 18 months of the trial were presented. Subsequent minor alterations in the conduct of the trial are discussed in the appropriate sections of this paper.

Briefly the trial was designed to measure changes in sward composition and productivity of a mixed pasture grazed by wether sheep under the following systems of management:

(a) Sheep grazing with natural return of droppings (F.R.)*
(b) Sheep grazing with no return of droppings (N.R.)*
(c) Sheep grazing with return of urine only (U.R.)*
(d) Sheep grazing with return of dung only (D.R.)*

* The initials F.R., N.R., U.R. and D.R. are used throughout the text in referring to the four treatments under trial

The pasture was sown in March, 1940, with a complex mixture of pedigree grasses and clovers. Superphosphate at 4 cwt. per acre was applied at sowing down and annually thereafter in April. Carbonate of lime at 10 cwt. per acre was applied at the same time in alternate years. Collections of dung and urine were made by the use of the harness and containers previously described (2).

Each treatment consisted of a pair of one tenth ($\frac{1}{10}$) acre paddocks, separately fenced, and so arranged that the block as a whole consisted of two comparable groups of four paddocks each.

When the pastures were ready for grazing the sheep were put on to one set of paddocks and measurements made within this group. After grazing was completed the sheep were transferred to the similar treatments in the duplicate set of paddocks. Depending on growth conditions, the sheep were then either returned to their first set of paddocks or else removed from the whole area to await the next grazing. It will therefore be appreciated that although each treatment consisted of a pair of separate paddocks, these two are not true duplicates since they were never grazed simultaneously. The small differences which would result should, however, be evened out over several grazings, and for the four year period covered in the trial, the two paddocks of each pair may justifiably be considered as valid duplicates.

For the first 2-3 years of the trial, grazings were carried out when the growth reached 2 to 3 inches and this was grazed down to about 1 inch in height. Due largely to shortage of collection gear, only small numbers of sheep were used at each grazing. Thus the management of the pastures was such as to produce good ryegrass-white clover swards, and since the sheep were on the paddocks for a large proportion of the time, total collections of dung and urine for the two paddocks of each treatment could be expected to be reasonably complete.

Later on, ample collection gear became available, but because of staff shortages and overlapping the work with other trials, it became necessary to reduce the number of grazings so that the pastures were generally 4 to 6 inches in length at the beginning of each grazing. This change in management favoured the growth of cocksfoot which came into prominence in all treatments towards the end of the trial. On the other hand the more lax grazing management was no doubt detrimental to the full development of the ryegrass. During this period larger numbers of sheep were used for shorter times on the paddocks ; between grazings they were held with the general Station sheep on feed that was probably not quite as plentiful. The dung and urine collected during grazing of the paddocks were probably not as true a reflection of the feed ingested as were the earlier collections. Also with the longer grass growth, some feed may have been wasted by trampling and fouling. The general overall effects of the treatments do not appear to have been significantly affected by the modification ; they are, however, probably the main reason for the poorer nutrient balances obtained in the last two years.

EXPERIMENTAL TECHNIQUE AND FERTILIZERS

Following the original dressings of 10 cwt. of lime and 4 cwt. of superphosphate per acre at the time of sowing and a further dressing with 4 cwt. of superphosphate in August 1941, the whole area was topdressed by hand as follows :—

April, 1942 :—Superphosphate at 4 cwt. per acre plus carbonate of lime at 10 cwt. per acre.

April, 1943 :—Superphosphate at 4 cwt. per acre. No lime.

April, 1944 :—Superphosphate at 4 cwt. per acre plus carbonate of lime at 10 cwt. per acre.

Pasture yields were determined throughout by the use of protecting cages as previously detailed. After the sheep had been removed from the paddock, the protected herbage was clipped, by hand, down to the same height as the grazed herbage.

Samples for botanical and chemical analyses were obtained by cutting 60-80 individual areas (each of approximately 30 square inches) per paddock prior to each grazing. These samples were then mixed and sub-sampled for analysis. Botanical analysis was made by direct dissection of the fresh herbage, the separations then being oven-dried and the composition determined on the dry matter basis. Chemical compositions of the herbage were determined by the methods previously described (1). Collections of dung and urine and their sampling continued as previously described, but in addition, complete collections were made from two sheep on each treatment for the 1941-42 season, to give a check on the chemical composition of the excrements for the different treatments, as well as to obtain a balance between ingestion and excretions for that period. The materials thus collected were measured, sampled and then returned to their appropriate paddocks e.g. on the full return treatment, two sheep only were collected from, and all collections were returned, while on the urine return treatment the dung was collected from all sheep, but in addition two sheep were harnessed for urine collection and this urine was sampled and then returned to its paddock.

The chemical analyses of the dung and urine followed the methods earlier described (1), but due to the very small amounts of calcium and phosphorus found previously in the urine samples, these constituents were not determined in the later stages of the trial.

For the chemical analysis of the herbage, the dung and the urine, the samples were bulked in proportion to the yields for the several measurements made within the periods shown, and the analysis made gives a direct figure for each period. Each period shown tallies with completed grazings of the experiment as a whole. The botanical analyses were, however, of necessity made on each sample as cut fresh after each paddock grazing, and then the dry weight percentages of the species present were determined. The calculations of the botanical compositions as shown for the periods covered by the chemical compositions, have been made by calculating the total weight of the various species for each particular paddock within that period. After addition of the two sets of total species yields for two paddocks of each treatment, these were then calculated as percentages of the total dry matter yields for the four treatments, and thus the botanical and chemical analyses are on the same sampling basis. No adjustment could, of course, be made for the final laboratory moisture figure, but as this is very small in itself, no significant error is introduced.

Results

The data secured have been summarized into a series of tables similar to those in the earlier paper. These are shown in detail for the period covered by this report (22nd July, 1941, to 30th May, 1944) but the totals quoted include also the results from 22nd July, 1940 to 21st July, 1941, and quoted in the earlier paper (1).

Table I sets out the monthly mean figures for soil temperatures at the 1 ft. level and the total monthly precipitations, together with departures from the previous ten-year averages. The relatively small overall range in soil temperatures (46-67 F.) together with the fairly even spread of rainfall, give a good picture of the excellent all-the-year-round growth conditions which normally occur at Palmerston North. The only outstanding feature of the weather for the period of the trial was the very hot autumn of 1944. At this time, high soil temperatures coincided with very low rainfall, and these conditions were reflected in much reduced pasture yields and a marked change in chemical composition.

TABLE I. METEOROLOGICAL DATA RECORDED AT GRASSLANDS DIVISION, PALMERSTON NORTH
(Station situated 10 chains from experimental block)

Month.	Soil Temperature at 1 ft.		Rainfall (Inches).	
	Mean for Month.	Departure from Ten Year Average, 1930-1940.	Total.	Departure from Ten Year Average, 1930-1940.
1941	°F.	°F.		
August	45.0	—1.9	2.95	—0.61
September	50.2	—0.3	2.92	—0.14
October	53.9	—1.0	5.19	+1.95
November	57.6	—1.4	4.59	+1.60
December	62.1	—1.5	4.62	+1.64
1942				
January	62.5	—3.7	3.96	+1.13
February	63.4	—1.1	3.43	+0.50
March	60.7	+0.4	4.47	+1.95
April	58.4	+2.2	1.86	—1.65
May	52.7	+1.1	4.93	+1.40
June	47.0	0.0	0.61	—3.29
July	48.2	+4.4	5.46	+2.71
August	47.8	+0.	2.88	—0.78
September	51.2	+0.7	4.04	+1.02
October	57.6	+2.7	1.93	—1.31
November	59.7	+0.7	3.09	+0.10
December	63.5	+0.1	1.65	—1.33
1943				
January	66.5	+0.3	2.60	—0.23
February	66.0	+1.5	5.75	+1.82
March	63.1	+2.8	1.06	+1.46
April	58.3	+2.1	2.04	—1.47
May	51.8	+0.2	1.33	—2.20
June	49.5	+2.5	6.59	+2.69
July	46.3	+2.5	4.22	+1.47
August	46.5	—0.4	2.63	—0.93
September	50.9	+0.5	5.70	+2.64
October	55.7	+0.8	3.48	+0.24
November	60.8	+1.8	1.97	—1.02
December	66.4	+0.8	1.98	—1.00
1944				
January	67.1	+0.9	1.39	—1.44
February	66.5	+2.0	1.15	—2.78
March	64.6	+4.3	3.51	+0.99
April	59.7	+3.5	3.35	—0.16
May	52.0	+0.4	1.25	—2.28
June	47.4	+0.4	3.11	—0.79
July	46.5	+2.7	1.67	—1.08

In Table II are shown the total dry matter yields as measured for each pair of paddocks within the treatments. Due to the fact that all chemical determinations were done on samples proportionately bulked from both paddocks of each treatment, the figures shown in Table II do not take into account the final moisture content determined in the laboratory analyses. The totals are therefore greater then those shown in subsequent tables by 3 to 5 per cent. Considering that the two paddocks within each treatment are not absolutely comparable because of the different grazing times, the agreement in total annual productions is reasonably good. The appended statistical analysis shows that the

treatment differences are highly significant between N.R. and F.R. and that U.R. and D.R. differ significantly from both N.R. and F.R., but with no significant difference in total productions between the U.R. and D.R. treatments themselves. The totals for the first year of the trial (22nd July, 1940, to 21st July, 1941) are included for completeness.

Table II. Total Dry Matter Yields of Duplicate Paddocks Within Treatments for Periods Shown

(All figures in lb. D.M. per acre before laboratory adjustment for residual moisture)

Treatment.	Date.	Yields of Paddocks. A	B	Treatment.	Date.	Yields of Paddocks. A	B
Full Return	22/7/40-21/7/41	14936	13666	Urine Return	22/7/40-21/7/41	12426	13914
	21/7/41-28/5/42	14498	16738		21/7/41-28/5/42	11712	10844
	28/5/42-20/5/43	13596	14343		28/5/42-20/5/43	14680	12414
	20/5/43-30/5/44	13974	15250		20/5/43-30/5/44	12928	11325
	Total for 4 years	57004	59997		Total for 4 years	51746	48497
	Average per year	14251	14999		Average per year	12936	12124
	Mean Annual Yields	14625			Mean Annual Yields	12530	
No Return	22/7/40-21/7/41	13535	10675	Dung Return	22/7/40-21/7/41	13158	12037
	21/7/41-28/5/42	11272	9841		21/7/41-28/5/42	12659	12322
	28/5/42-20/5/43	9659	9575		28/5/42-20/5/43	13074	13226
	20/5/43-30/5/44	10834	11824		20/5/43-30/5/44	14233	12513
	Total for 4 years	45300	41915		Total for 4 years	53124	50098
	Average per year	11325	10479		Average per year	13281	12524
	Mean Annual Yields	10902			Mean Annual Yields	12903	

Analysis of Variance

Total Dry Matter Yields of Duplicate Paddocks within Treatments (Table II)

Source of Variation.	Degrees of Freedom.	Mean Square $\times 10^{-2}$	F.
Blocks	1	13890	
Treatments	3	186742	15.446
Years	3	5326	
Blocks × Treatments	3	12090	
Blocks × Years	3	2678	
Treatments × Years	9	17426	
Blocks × Treatments × Years	9	13009	
Total	31		

Significance of Differences between Treatment Means

	Full Return.	No Return.	Urine Return.	Dung Return.
Full Return	—	S.S.	S	S
No Return	—	—	S	S
Urine Return	—	—	—	N.S.

Table III sets out the complete period totals for pasture production and the botanical and chemical compositions determined for those periods. The yields are totals (on a per acre basis) for the duplicate paddocks, and include all cuts actually made within each period.

The seasonal variations in growth can be seen, although the periods are not of equal intervals such as would show this more clearly. The data have, however, been regrouped to show the point more clearly in Table VI. Similarly, variations in botanical compositions can be seen for each period.

TABLE III. YIELDS OF HERBAGE FROM THE TREATMENTS, AND DETAILS OF CHEMICAL AND BOTANICAL ANALYSES AT EACH SAMPLE BULKING DATE

Date.	Dry Matter per Acre in Pounds.	Botanical Composition (per cent. Dry Matter).					Ratio of Grasses to Clovers.	Chemical Analyses (per cent. Dry Matter).				
		Perennial Ryegrass.	Other Grasses.	White Clover.	Red Clover.	Other Species.		Total N.	Soluble Ash.	CaO.	P_2O_5.	K_2O.
A. Full Return												
9/8/41	439	80	4	14	2	—	5.3 : 1	4.26	7.90	0.80	1.11	3.90
19/9/41	2308	68	4	25	T	3	2.9 : 1	4.36	8.59	0.93	1.06	4.11
18/10/41	1441	68	11	20	1	—	3.3 : 1	4.38	10.97	1.14	1.43	4.85
3/12/41	2920	67	10	21	2	—	3.0 : 1	4.33	9.58	1.19	1.08	4.44
19/12/41	1786	51	6	37	6	—	1.3 : 1	4.71	10.07	1.30	1.09	4.46
26/1/42	2067	46	9	41	2	2	1.3 : 1	4.76	10.05	1.39	1.10	4.47
17/2/42	1764	59	4	33	T	4	1.9 : 1	4.52	10.65	1.23	1.06	4.86
16/3/42	1139	52	3	42	T	3	1.3 : 1	4.68	9.67	1.36	0.99	4.56
16/4/42	1098	60	3	37	T	—	1.7 : 1	4.39	10.52	1.11	1.08	4.67
28/5/42	658	59	5	30	T	6	2.1 : 1	4.51	9.93	1.08	0.96	4.56
30/7/42	1346	70	12	18	T	—	4.6 : 1	4.35	9.12	0.94	1.17	4.13
10/9/42	1460	57	20	21	—	2	3.7 : 1	4.27	9.35	1.07	1.16	4.18
23/10/42	2725	68	9	21	T	2	3.7 : 1	4.75	9.92	1.01	1.11	3.60
15/11/42	850	68	20	7	T	5	12.6 : 1	4.40	9.49	1.11	1.02	4.21
19/12/42	2811	61	12	24	T	3	3.0 : 1	4.21	9.40	1.18	0.91	3.91
26/2/43	2736	54	10	28	2	6	2.1 : 1	4.70	9.73	1.26	1.05	3.44
26/3/43	1143	57	7	35	1	T	1.8 : 1	4.35	10.25	0.98	0.93	4.41
20/5/43	900	77	9	14	T	T	6.2 : 1	4.16	9.22	1.04	0.76	3.76
2/9/43	1828	71	21	6	T	2	15.3 : 1	4.28	8.28	0.66	0.94	3.70
5/10/43	1747	68	15	15	—	2	5.6 : 1	5.13	9.68	1.01	1.52	4.30
26/10/43	1537	67	16	16	—	1	5.2 : 1	4.60	9.81	0.92	1.41	4.39
11/11/43	1211	56	25	16	—	3	5.1 : 1	4.18	9.63	0.88	1.13	4.28
19/12/43	2571	42	27	22	1	8	3.0 : 1	3.17	7.99	0.91	0.86	4.13
25/2/44	1405	63	16	19	2	T	3.8 : 1	3.21	7.48	1.33	0.65	2.73
27/3/44	732	52	11	21	6	T	1.7 : 1	4.33	8.52	1.18	0.87	3.50
19/4/44	996	69	7	24	T	T	3.2 : 1	4.76	9.03	1.05	1.02	3.99
30/5/44	785	70	11	19	—	T	4.3 : 1	4.69	9.07	0.74	1.04	3.94
B. No Return												
9/8/41	99	50	8	38	4	T	1.4 : 1	3.16	8.02	1.27	0.57	3.23
18/9/41	No Grazing	—	—	—	—	—	—	—	—	—	—	—
18/10/41	1712	32	6	60	2	T	0.5 : 1	4.11	10.12	1.74	1.32	3.92
3/12/41	2184	34	9	50	7	T	0.8 : 1	4.56	9.18	1.47	1.12	3.93
19/12/41	1132	22	7	54	17	—	0.4 : 1	4.86	9.14	1.49	1.09	3.61
26/1/42	1576	23	11	56	10	T	0.5 : 1	4.64	10.34	1.39	1.15	4.39
17/2/42	1173	50	8	38	4	T	1.4 : 1	4.57	9.17	1.47	1.08	3.62
16/3/42	1155	58	4	34	3	1	1.7 : 1	4.48	8.59	1.41	0.97	3.59
16/4/42	883	47	9	42	2	T	1.3 : 1	4.27	9.51	1.23	1.01	3.87
28/5/42	643	50	11	36	1	2	1.7 : 1	3.46	8.93	1.18	0.85	3.75

Table III. Yields of Herbage from the Treatments, and Details of Chemical and Botanical Analyses at Each Sample Bulking Date—(Continued)

Date.	Dry Matter per Acre in Pounds.	Botanical Composition (per cent. Dry Matter).					Ratio of Grasses to Clovers.	Chemical Analyses (per cent. Dry Matter).				
		Perennial Ryegrass.	Other Grasses.	White Clover.	Red Clover.	Other Species.		Total N.	Soluble Ash.	CaO.	P_2O_5.	K_2O.
30/7/42	991	60	15	25	T	—	3.0 : 1	4.31	8.70	1.02	1.23	3.72
10/9/42	902	42	15	41	T	2	1.4 : 1	4.05	8.22	1.42	1.07	2.91
23/10/42	1835	50	10	37	1	2	1.6 : 1	4.72	8.40	1.40	1.12	2.86
15/11/42	730	41	19	34	3	3	1.6 : 1	4.47	8.32	1.43	1.02	2.88
19/12/42	2136	34	14	44	6	2	1.0 : 1	4.99	8.62	1.73	1.05	2.99
26/2/43	2256	24	7	62	6	1	0.5 : 1	4.59	8.93	1.44	0.90	2.65
26/3/43	803	26	20	50	3	1	0.9 : 1	4.90	8.82	1.40	0.84	3.09
20/5/43	466	53	14	32	T	1	2.0 : 1	4.06	7.95	1.23	0.79	2.64
2/9/43	1257	55	28	17	T	T	4.9 : 1	4.02	8.45	1.04	0.88	2.91
5/10/43	1506	41	18	40	T	1	1.5 : 1	4.97	8.82	1.54	1.38	3.24
26/10/43	1197	42	17	41	T	T	1.4 : 1	4.59	8.35	1.23	1.06	3.11
11/11/43	955	34	20	42	1	3	1.0 : 1	4.32	8.18	1.14	1.14	3.04
19/12/43	2582	33	20	44	3	—	1.1 : 1	4.05	7.93	1.54	0.94	3.23
25/2/44	1157	29	11	32	28	T	0.7 : 1	3.36	7.60	1.70	0.67	2.57
27/3/44	691	48	12	29	11	—	1.5 : 1	4.28	7.77	1.34	0.76	3.06
19/4/44	742	48	17	34	1	—	1.9 : 1	4.83	8.02	1.13	0.86	3.21
30/5/44	426	57	15	25	T	3	2.9 : 1	4.42	7.94	0.78	0.77	2.83
C. Urine Return												
9/8/41	239	76	10	13	1	T	6.1 : 1	3.67	7.47	0.80	0.67	3.40
18/9/41	1272	72	4	21	T	3	3.6 : 1	4.37	8.44	1.08	0.89	3.79
18/10/41	1171	61	6	29	2	2	2.1 : 1	4.46	10.03	1.19	1.50	4.80
3/12/41	2028	55	9	32	4	T	1.8 : 1	4.54	9.42	1.21	1.06	4.23
19/12/41	1459	31	8	51	10	—	0.6 : 1	4.73	9.71	1.31	1.03	4.36
26/1/42	1606	39	6	46	9	T	0.8 : 1	4.33	10.18	1.29	0.94	4.56
17/2/42	1273	49	4	44	3	T	1.1 : 1	4.62	10.33	1.35	0.95	4.52
16/3/42	825	47	4	44	1	4	1.1 : 1	4.74	9.56	1.40	0.87	4.08
16/4/42	815	52	7	41	T	T	1.4 : 1	4.34	10.26	1.13	1.01	4.54
28/5/42	594	54	4	42	T	T	1.4 : 1	4.35	9.43	1.06	0.82	4.11
30/7/42	1354	66	17	17	T	—	4.9 : 1	4.33	8.97	1.02	1.18	3.70
10/9/42	1401	54	13	33	—	T	2.0 : 1	3.97	9.00	1.28	1.07	3.25
23/10/42	2703	60	10	29	1	T	2.5 : 1	4.79	9.46	1.19	1.01	3.95
15/11/42	923	69	16	13	T	2	6.6 : 1	4.65	9.78	1.34	0.96	3.87
19/12/42	2785	58	7	33	2	T	1.9 : 1	4.76	9.66	1.42	0.93	3.88
26/2/43	2616	44	8	46	1	1	1.1 : 1	4.59	9.17	1.17	0.99	3.79
26/3/43	1000	53	7	39	1	T	1.5 : 1	4.64	9.52	1.28	0.76	3.88
20/5/43	762	61	11	28	T	T	2.6 : 1	4.09	8.50	1.05	0.77	3.18

TABLE III. YIELDS OF HERBAGE FROM THE TREATMENTS, AND DETAILS OF CHEMICAL AND BOTANICAL ANALYSES AT EACH SAMPLE BULKING DATE—(Continued)

Date.	Dry Matter per Acre in Pounds.	Botanical Composition (per cent. Dry Matter).					Ratio of Grasses to Clovers.	Chemical Analyses (per cent. Dry Matter).				
		Perennial Ryegrass.	Other Grasses.	White Clover.	Red Clover.	Other Species.		Total N.	Soluble Ash.	CaO.	P_2O_5.	K_2O.
2/9/43	1314	62	17	21	—	—	3.8 : 1	4.15	8.60	0.97	0.99	3.31
5/10/43	1933	49	15	36	T	T	1.8 : 1	5.33	10.16	1.51	1.56	3.91
26/10/43	1449	60	13	26	1	T	2.7 : 1	4.80	9.70	1.11	1.18	4.27
11/11/43	1106	52	17	31	T	T	2.2 : 1	4.52	9.75	1.02	0.99	4.00
19/12/43	2450	38	37	21	2	2	3.3 : 1	3.60	8.57	1.07	0.73	4.29
25/2/44	1063	24	20	45	8	3	0.8 : 1	3.28	7.62	1.41	0.54	2.75
27/3/44	511	50	10	35	5	—	1.5 : 1	4.50	8.40	1.24	0.80	3.48
19/4/44	900	53	11	35	—	1	1.8 : 1	4.87	9.17	0.99	0.79	3.96
30/5/44	477	70	12	18	—	T	4.6 : 1	4.27	8.45	0.72	0.80	3.28
D. Dung Return												
9/8/41	326	52	8	36	4	T	1.5 : 1	3.66	7.79	1.21	0.96	3.01
18/9/41	1266	43	11	43	3	T	1.2 : 1	4.58	8.20	1.44	1.09	3.44
18/10/41	1047	36	19	40	5	T	1.2 : 1	4.50	9.92	1.43	1.51	3.94
3/12/41	2256	46	19	31	4	T	1.9 : 1	4.32	9.02	1.27	1.22	4.31
19/12/41	1484	28	13	49	10	T	0.7 : 1	4.76	9.26	1.47	1.14	3.73
26/1/42	1691	30	21	39	10	T	1.0 : 1	4.53	9.59	1.46	1.14	3.80
17/2/42	1153	45	11	42	2	T	1.3 : 1	4.47	9.12	1.43	1.09	3.73
16/3/42	1433	42	7	47	2	2	1.0 : 1	4.49	8.92	1.44	1.02	3.67
16/4/42	1259	49	12	38	T	1	1.6 : 1	3.99	9.28	1.14	1.03	3.52
28/5/42	577	62	11	25	T	2	2.9 : 1	4.42	9.27	1.21	1.03	3.86
30/7/42	1665	58	22	20	T	—	4.0 : 1	4.38	8.46	1.06	1.27	3.41
10/9/42	1411	54	19	24	1	2	2.9 : 1	3.99	8.33	1.22	1.11	3.00
23/10/42	2355	57	18	23	1	1	3.1 : 1	4.40	8.43	1.20	1.19	3.24
15/11/42	795	44	24	30	1	1	2.2 : 1	4.14	8.65	1.33	1.16	3.04
19/12/42	2472	38	22	40	2	3	1.3 : 1	4.91	8.56	1.55	1.06	3.09
26/2/43	2795	27	25	39	9	T	1.1 : 1	4.83	8.84	1.37	1.13	3.06
26/3/43	945	32	29	36	1	2	1.7 : 1	4.87	8.86	1.28	1.01	3.26
20/5/43	719	60	22	16	1	1	4.9 : 1	3.99	8.26	1.24	0.85	2.86
2/9/43	1749	46	44	10	—	T	9.0 : 1	4.38	8.44	0.95	1.04	3.37
5/10/43	1529	59	20	21	T	—	3.8 : 1	4.96	8.67	1.29	1.46	3.38
26/10/43	1373	40	22	37	T	1	1.7 : 1	4.44	8.63	1.05	1.26	3.43
11/11/43	1074	36	30	31	1	2	2.1 : 1	3.99	8.54	1.01	1.17	3.27
19/12/43	2386	35	29	31	3	2	1.9 : 1	3.59	7.86	1.26	0.95	3.56
25/2/44	1446	28	27	30	15	T	1.2 : 1	3.28	7.15	1.65	0.62	2.36
27/3/44	698	42	25	26	5	2	2.2 : 1	4.23	7.71	1.30	0.76	2.97
19/4/44	926	42	18	39	1	—	1.5 : 1	4.63	8.03	1.19	0.87	3.15
30/5/44	718	73	9	17	T	1	4.8 : 1	4.74	8.21	0.94	1.05	3.40

The seasonal rise and fall of the proportion of clovers to grasses is clearly seen. White clover production is low during the winter and rises to a maximum during the October-December periods. It is to be noted however that red clover declined markedly in importance after the first year, and showed up again only in the dry autumn of 1944. The increase in "Other grasses" is most marked and is probably associated with the change in management already mentioned. This increase was due largely to cocksfoot, the growth of which was most pronounced in the D.R. paddocks where grazing was not so severe from the beginning of the trial. Its growth was also favoured by lack of competition from ryegrass during the early stages of the trial (1).

When the ratios of total grasses to total clovers are compared, the position is even more clearly defined, as this eliminates the small proportion of weeds and the confusion of the various grass and clover species themselves.

Considering the chemical compositions of the herbage, there are similar changes throughout the seasons depending, no doubt, largely on the proportions of grasses to clovers. Thus where the clover growth increases, there is a rise in the calcium figure. Potash is higher in both the F.R. and U.R. treatments throughout and is probably the result of the larger quantities of available potash returned in the urine. These treatments however, show grass dominance as compared with the N.R. and the D.R., and the average higher percentage of potash in grass is probably a contributing factor.

The seasonal variability in chemical composition of pastures is well demonstrated in Table III. Thus the nitrogen (N) ranges from 3.16 to 5.33 per cent., calcium (CaO) from 0.66 to 1.74 per cent., phosphorus (P_2O_5) from 0.54 to 1.56 per cent. and potassium (K_2O) from 2.36 to 4.86 per cent. It is obviously difficult to draw any simple conclusion from such a variable set of figures, governed as it is by both botanical composition and growth conditions through the year. However, it is of considerable interest to note the low percentages recorded in all treatments in the summer of 1944 (the period 19th December, 1943, to 25th February, 1944), for all constituents other than calcium.

Table IV sets out the annual totals for the four year period. Total yields of botanical and chemical constituents have been calculated from the individual cut yields and the analyses of the bulked samples for the periods shown in Table III. In Table V these total production figures have been reduced to percentages, whilst the total dry matter productions are shown as relative quantities when the mean annual yield of the N.R. treatment is equated to 100. Considering these two tables together it can be seen that the yield of the N.R. paddocks has remained fairly constant at between 10,100 and 11,000 lb. dry matter per acre. This in itself is a very high yield and clearly shows the growth capabilities of a soil under good climatic conditions when good clovers and grasses are used and adequately fed with phosphates and lime. It is rather interesting that the annual yield of phosphorus is very close to the amount of phosphorus in the added superphosphate, but as there are no comparative plots without phosphate or without clovers, the value of these two in producing the strong growth of pasture as a whole cannot be assessed. Trials are at present under way at Palmerston North and Lincoln to obtain figures on this aspect.

TABLE IV. TOTAL YIELDS OF DRY MATTER AND BOTANICAL AND CHEMICAL CONSTITUENTS FOR THE TREATMENTS OVER THE FOUR YEAR PERIOD

Treatment.	Period.	Total Dry Matter (lb. per Acre).	Total Species Yields per Acre (in pounds).					Total Nutrients per Acre (in pounds).				
			Perennial Ryegrass.	Other Grasses.	White Clover.	Red Clover.	Other Species.	N.	Soluble Ash.	CaO.	P_2O_5.	K_2O.
Full Return	22/7/40-21/7/41	13675	8903	651	2636	1236	249	643.5	1247.1	151.7	145.1	556.6
	21/7/41-28/5/42	15620	9399	1027	4711	229	254	702.2	1537.2	184.5	171.9	701.6
	28/5/42-20/5/43	13971	8742	1642	3146	66	375	621.7	1340.9	153.5	143.2	538.7
	20/5/43-30/5/44	12812	7777	2350	2259	98	328	531.6	1121.9	121.5	135.2	502.8
	Total	56078	34821	5670	12752	1629	1206	2499.0	5247.1	611.2	595.4	2299.7
	Average per year	14019	8705	1417	3188	407	302	624.8	1311.8	152.8	148.9	574.9
No Return	22/7/40-21/7/41	11140	4241	659	3609	2063	568	437.0	998.3	160.6	117.6	406.3
	21/7/41-28/5/42	10557	3946	849	5091	647	24	492.9	996.4	154.0	116.4	408.5
	28/5/42-20/5/43	10119	3914	1288	4434	327	156	466.8	868.5	145.4	103.0	297.4
	20/5/43-30/5/44	10513	4253	1933	3774	496	57	449.2	856.7	142.4	102.6	321.7
	Total	42329	16354	4729	16908	3533	805	1845.9	3719.9	602.4	439.6	1433.9
	Average per year	10582	4089	1182	4227	883	201	461.5	929.9	150.6	109.9	358.5
Urine Return	22/7/40-21/7/41	12586	7602	729	2821	1049	385	588.0	1151.8	146.7	127.8	529.4
	21/7/41-28/5/42	11282	5762	705	4276	444	95	506.3	1089.0	138.1	114.5	487.7
	28/5/42-20/5/43	13544	7672	1388	4321	119	44	616.9	1262.5	167.2	132.5	508.3
	20/5/43-30/5/44	11203	5459	2214	3265	175	90	487.4	1014.5	129.1	109.8	428.5
	Total	48615	26495	5036	14683	1787	614	2198.6	4517.8	581.1	484.6	1953.9
	Average per year	12154	6624	1259	3671	447	153	549.6	1129.4	145.3	121.1	488.5
Dung Return	22/7/40-21/7/41	12342	4024	570	4157	3257	334	493.7	1118.1	172.6	134.6	462.1
	21/7/41-28/5/42	12492	5147	1783	4945	563	54	553.2	1039.4	170.8	142.5	473.8
	28/5/42-20/5/43	13157	5724	2923	3987	365	158	596.8	1127.4	171.3	147.4	412.9
	20/5/43-30/5/44	11899	5088	3189	3173	344	105	495.8	968.4	142.3	123.0	386.1
	Total	49890	19983	8465	16262	4529	651	2139.5	4253.3	657.0	547.5	1734.9
	Average per year	12472	4996	2116	4065	1132	163	534.9	1063.3	164.2	136.9	433.7

Where urine and dung have been returned, the increase in yield has been 15 per cent. and 18 per cent. respectively and where both were returned the increase was 33 per cent., a very interesting coupling effect, quite apart from the degrees of increase themselves. Urine stimulated the grass in the early stages of the trial but the grass to clover ratio subsequently declined. This may possibly have been due to the drain of phosphate in the discarded dung and to the fact that, although there was ample nitrogen being returned in the urine, there was insufficient phosphate applied as superphosphate to allow the grasses to take full advantage of the other nutrients. There is no definite evidence of this from the trial itself, but the decrease in the grass to clover ratio, together with the relatively low phosphorus figure for the herbage as a whole is suggestive.

The dung gave no immediate stimulation to the grass constituents but acted largely to give increased clover growth in the early stages. The grass to clover ratio later increased, presumably due to action of the less soluble nitrogen constituents, and also to transference in the soil of nitrogen compounds from the clover-nodules to the grass plants. It is seen that the ratio of grasses to clovers rose from 0.62 : 1 to 2.35 : 1 over the four year period. The effect of returning the phosphate in the dung is reflected in the generally higher level of phosphorus than in the N.R. treatment where the botanical composition is somewhat similar, the average extra uptake of phosphorus being 27 lb. per annum. There is only a small difference to be seen in the total calcium figures, and presumably the added lime gave adequate supplies of this to all treatments, irrespective of the quantities in the droppings returned. The potash totals and percentages appear definitely greater than in the N.R. treatment, but are probably associated as much with the rising grass percentage as with the amount of returned potash in the dung.

In the F.R. treatment there is an overall increase in the grass constituents, and while the proportion of clovers is much lower than in the N.R. treatment, the difference in absolute amounts is not as marked. The absolute uptake of nutrients is greatest in all the constituents other than calcium, of which the greatest amount was taken up in the D.R. treatment. In this latter, however, there was not only a much greater total amount of clover (with less grass competition due to the lack of urine nitrogen) but also a similar return of calcium in the dung.

The seasonal spreads of production are shown in Table VI. The percentage figures shown have been calculated directly from the data in Table III by assuming that daily growth rates within a period were the same. By this means some period yields were divided to fit them into the seasonal groupings. This assumption is no doubt incorrect for single analyses, but probably gives a reasonable figure for the total four year period.

It can be seen that there is a better seasonal spread with the higher yielding paddocks, although the figures are not as impressive as early observations and figures indicated. Possibly, however, this latter impression was confused by the absolute amounts of herbage available in the different seasons. There is also the strong possibility that the ryegrass element in the return treatments was somewhat inhibited in development by the more lax grazing management towards the end of the trial. This would affect the seasonal spread markedly because of the

TABLE V. RELATIVE DRY MATTER YIELDS AND BOTANICAL AND CHEMICAL COMPOSITIONS FOR THE TREATMENTS OVER THE FOUR YEAR PERIOD

Treatment.	Period.	Relative Dry Matter. Av. N.R. = 100.	Botanical Composition (per cent. Dry Matter).					Ratio of Grasses to Clovers.	Chemical Composition (per cent. Dry Matter).				
			Perennial Ryegrass.	Other Grasses.	White Clover.	Red Clover.	Other Species.		N.	Soluble Ash.	CaO.	P_2O_5.	K_2O.
Full Return	22/7/40-21/7/41	129.4	65.2	4.7	19.3	9.1	1.7	2.46 : 1	4.70	9.12	1.11	1.06	4.08
	21/7/41-28/5/42	147.8	60.1	6.6	30.2	1.5	1.6	2.10 : 1	4.49	9.84	1.18	1.10	4.49
	28/5/42-20/5/43	132.1	62.6	11.7	22.5	0.5	2.7	3.23 : 1	4.44	9.60	1.10	1.02	3.85
	20/5/43-30/5/44	121.1	60.7	18.3	17.6	0.8	2.6	4.29 : 1	4.15	8.75	0.95	1.06	3.92
	Total Period	132.6	62.1	10.1	22.7	2.9	2.2	2.8 : 1	4.46	9.34	1.09	1.06	4.10
No Return	22/7/40-21/7/41	105.4	38.0	5.9	32.5	18.5	5.1	0.85 : 1	3.92	8.96	1.44	1.06	3.64
	21/7/41-28/5/42	99.8	37.4	8.1	48.2	6.1	0.2	0.84 : 1	4.67	9.44	1.46	1.10	3.87
	28/5/42-20/5/43	95.7	38.7	12.7	43.8	3.2	1.6	1.09 : 1	4.61	8.58	1.44	1.02	2.94
	20/5/43-30/5/44	99.4	40.5	18.4	35.9	4.7	0.5	1.45 : 1	4.27	8.15	1.35	0.97	3.06
	Total Period	100	38.6	11.2	39.9	8.4	1.9	1.0 : 1	4.36	8.79	1.42	1.04	3.39
Urine Return	22/7/40-21/7/41	119.0	60.4	5.8	22.4	8.3	3.1	2.16 : 1	4.67	9.15	1.16	1.02	4.20
	21/7/41-28/5/42	106.6	51.1	6.2	37.9	3.9	0.9	1.37 : 1	4.49	9.65	1.22	1.01	4.32
	28/5/42-20/5/43	128.1	56.6	10.2	31.9	0.9	0.4	2.04 : 1	4.55	9.32	1.23	0.98	3.75
	20/5/43-30/5/44	106.0	48.7	19.8	29.1	1.6	0.8	2.23 : 1	4.35	9.06	1.15	0.98	3.82
	Total Period	114.9	54.5	10.4	30.2	3.7	1.2	1.9 : 1	4.52	9.29	1.19	1.00	4.02
Dung Return	22/7/40-21/7/41	116.8	32.6	4.6	33.7	26.4	2.7	0.62 : 1	4.00	9.06	1.40	1.09	3.74
	21/7/41-28/5/42	118.1	41.2	14.3	39.6	4.5	0.4	1.28 : 1	4.43	8.32	1.37	1.14	3.79
	28/5/42-20/5/43	124.3	43.5	22.2	30.3	2.8	1.2	1.98 : 1	4.54	8.57	1.30	1.12	3.14
	20/5/43-30/5/44	112.6	42.8	26.8	26.7	2.9	0.8	2.35 : 1	4.17	8.14	1.20	1.03	3.24
	Total Period	117.8	40.0	17.0	32.6	9.1	1.3	1.4 : 1	4.29	8.53	1.31	1.10	3.48

lack of that species (ryegrass) which performs so relatively well in the late autumn and winter periods. It will be appreciated that the greater winter percentages and the better overall spreads of the higher producing paddocks is a factor of considerable practical importance.

The outstanding feature of the whole set of figures is, of course, the general excellence of the spread in all treatments. Important as is the better spread of production when animal droppings are returned, the high productivity of the N.R. treatment when topdressed adequately with lime and phosphate and grown under good climatic conditions cannot be overlooked. The part played by the pedigree white clover growing under conditions which are ideal for its full expression, will readily be appreciated. Trials are in progress to obtain measurements on this aspect and the effect on associated grass growth.

There are, on the other hand, certain stock feeding difficulties apparently associated with clover dominance (notably bloat), and thus the production record itself cannot be the only guide to the ideal pasture sward, which appears to have grass dominance as its main criterion.

Table VI. Seasonal Spread of Total Dry Matter Production for the Treatments over the Four Year Period

(All yields as per cent. total annual production of Dry Matter)

Treatment.	Season.	Spring. (Aug.-Oct.)	Summer. (Nov.-Jan.)	Autumn. (Feb.-April)	Winter. (May-July)
Full Return					
	1940-41	24.2	32.0	34.4	9.4
	1941-42	28.8	35.8	20.6	14.8
	1942-43	30.3	30.0	28.7	11.0
	1943-44	30.8	35.8	19.8	13.6
	Weighted Av. for 4 years	28.6	33.4	25.7	12.3
No Return					
	1940-41	31.1	38.6	31.5	2.7
	1941-42	21.9	32.2	32.3	13.7
	1942-43	29.7	39.1	20.5	10.7
	1943-44	30.4	41.4	19.0	9.2
	Weighted Av. for 4 years	28.3	37.8	25.0	8.9
Urine Return					
	1940-41	26.6	34.4	32.0	7.0
	1941-42	25.2	36.4	24.6	13.8
	1942-43	33.6	36.6	20.3	9.5
	1943-44	34.0	38.8	15.5	11.7
	Weighted Av. for 4 years	29.8	36.5	23.3	10.4
Dung Return					
	1940-41	28.1	36.3	29.6	6.0
	1941-42	22.5	34.5	28.6	14.4
	1942-43	33.0	33.0	21.1	13.0
	1943-44	30.0	39.1	18.3	12.6
	Weighted Av. for 4 years	28.2	35.6	24.6	11.6

In Tables VII and VIII are detailed the dung and urine collections and their analyses. Full collections were carried out on the N.R. treatment throughout, and also the urine and dung from the D.R. and N.R. treatments respectively. In addition, two pilot sheep were measured fully on all treatments for the 1941-42 season. The quantitative figures for the dry matter in the dung are related to the corresponding period dry matter yields of the herbage, but the ratios for longer terms should be taken to obtain a better figure for dry matter digestibilities. The quantitative figures for urine are much more erratic, and as would be expected, are more dependent on rainfall and surface moisture conditions.

TABLE VII. DETAILS OF DUNG AND URINE COLLECTIONS FROM THE TREATMEMTS, FOR THE PERIODS SHOWN

Period.	Dung Collections.						Urine Collections.		
	Dry Matter (Pounds per Acre).	Chemical Comp. (per cent. Dry Matter).					Pounds per Acre.	Chemical Comp. (per cent. Dry Matter).	
		N.	Sol. Ash.	CaO.	P_2O_5.	K_2O.		N.	K_2O.
Full Return									
22/7/41-9/8/41	75	3.0	13.6	3.8	3.7	2.8	721	1.36	0.96
18/9/41	389	3.1	13.4	4.3	3.6	1.7	5292	0.85	1.05
18/10/41	437	3.3	14.5	4.2	4.7	2.7	2889	0.97	0.88
3/12/41	605	3.5	14.9	4.5	4.6	2.1	7940	0.73	1.04
19/12/41	311	3.5	14.3	4.6	4.3	1.8	4842	1.01	1.59
26/1/42	484	3.5	13.7	4.7	4.1	1.5	5142	0.87	1.20
17/2/42	391	3.5	14.1	5.0	3.8	1.2	5263	1.18	1.54
16/3/42	495	3.0	13.0	4.7	3.5	0.8	3481	0.99	1.35
16/4/42	341	3.4	15.8	3.6	3.7	2.2	3935	0.63	0.88
28/5/42	374	3.5	15.1	2.4	2.1	1.5	3284	0.86	0.76
No Return									
22/7/41-9/8/41	48	2.7	12.6	3.1	2.8	2.8	347	0.95	0.76
18/9/41	No Grazing	—	—	—	—	—	—	—	—
18/10/41	338	3.1	15.5	5.7	4.5	1.3	4932	0.57	0.66
3/12/41	445	3.4	14.9	5.4	4.2	1.5	4811	0.70	0.93
19/12/41	304	3.4	14.9	5.6	4.2	1.4	3067	1.01	1.51
26/1/42	343	3.3	15.4	5.8	4.2	1.3	3009	0.87	1.15
17/2/42	264	3.4	15.1	5.6	3.9	1.3	2216	1.20	1.77
16/3/42	295	3.0	13.4	4.9	3.1	1.0	2833	1.13	1.42
16/4/42	193	3.0	14.5	4.8	3.8	1.3	2405	0.74	0.87
28/5/42	166	2.5	11.3	3.0	2.5	1.2	1983	0.59	0.65
21/5/43-2/9/43	281	3.2	14.4	4.9	3.5	1.2	2511	0.99	0.83
5/10/43	338	2.9	16.4	5.3	5.4	1.2	3115	0.91	0.83
26/10/43	226	3.0	13.9	4.1	4.0	1.2	2509	0.75	0.85
11/11/43	146	3.0	14.2	4.5	4.8	1.1	1676	0.92	0.91
19/12/43	500	3.1	12.7	4.9	3.2	1.2	3482	1.11	1.24
25/2/44	447	2.6	12.0	5.1	1.6	0.8	1496	1.54	1.67
27/3/44	180	3.0	12.5	4.6	2.9	0.9	1436	1.04	1.02
19/4/44	130	2.9	12.7	3.9	3.0	0.9	1262	1.10	1.01
30/5/44	97	2.8	12.5	3.4	3.8	1.3	1580	0.77	0.80
Urine Return									
22/7/41-9/8/41	61	2.8	13.0	3.5	3.1	1.7	467	1.03	0.90
18/9/41	159	3.4	13.7	4.8	3.6	1.8	2927	0.77	1.24
18/10/41	294	3.2	15.8	5.2	5.2	1.9	3195	0.64	0.72
3/12/41	525	3.5	14.1	4.8	4.1	1.7	5540	0.70	1.11
19/12/41	316	3.4	14.3	5.1	4.0	1.6	3162	1.03	1.39
26/1/42	366	3.3	14.5	5.4	3.9	1.4	4392	0.91	1.52
17/2/42	278	3.2	14.0	5.1	3.6	1.4	3092	1.13	1.69
16/3/42	369	2.9	12.9	4.6	3.0	1.1	3560	0.99	1.37
16/4/42	189	3.0	14.3	4.4	3.7	1.6	1954	0.69	0.85
28/5/42	169	2.4	11.3	3.0	2.2	1.1	2595	0.61	0.69
21/5/43-2/9/43	269	3.1	14.5	4.4	3.6	1.7			
5/10/43	247	3.2	16.5	5.3	5.7	1.5			
26/10/43	274	3.1	14.2	4.1	4.0	1.6			
11/11/43	161	3.2	13.4	4.2	4.8	1.5	Not Collected or sampled.		
19/12/43	617	3.1	12.0	4.2	3.1	1.4			
25/2/44	568	2.5	11.4	4.3	1.2	1.6			
27/3/44	245	2.9	12.9	4.6	2.3	1.5			
19/4/44	153	2.9	12.7	3.9	2.7	1.2			
30/5/44	95	2.8	11.3	3.1	2.8	1.0			
Dung Return									
22/7/41-9/8/41	45	3.0	13.2	4.1	3.2	1.1	678	1.01	0.81
18/9/41	237	3.3	13.6	4.6	3.7	1.3	2392	0.82	1.29
18/10/41	232	3.2	16.5	5.3	5.2	2.1	2978	0.72	0.77
3/12/41	507	3.4	14.5	4.8	4.6	1.7	5722	0.70	1.05
19/12/41	274	3.4	14.6	5.1	4.5	1.4	2730	1.12	1.45
26/1/42	291	3.4	14.8	5.3	4.5	1.1	3406	1.02	1.33
17/2/42	323	3.4	14.4	5.4	3.9	1.0	2564	1.22	1.69
16/3/42	323	3.0	13.1	4.8	3.3	0.9	3074	1.03	1.35
16/4/42	200	3.3	15.3	4.6	4.2	1.5	2881	0.73	0.92
28/5/42	258	2.6	11.5	3.0	2.8	1.1	2182	0.72	0.64
21/5/43-2/9/43							2905	1.04	0.91
5/10/43							2760	1.02	0.94
26/10/43							3101	0.76	0.91
11/11/43			Not Collected or sampled.				1742	0.83	0.81
19/12/43							3050	1.15	1.30
25/2/44							1523	1.47	1.49
27/3/44							1538	1.14	1.02
19/4/44							1602	1.19	1.08
30/5/44							1706	0.93	0.86

TABLE VIII. TOTAL AMOUNTS OF NUTRIENTS IN DUNG, AND SOLUBLE ASH IN THE DUNG AND URINE ESTIMATED TO HAVE BEEN PRODUCED DURING THE PERIODS SHOWN

(All weights in pounds per acre)

Treatment.	Period.	Dung.						Urine.		
		Total D.M. per acre.	N.	Sol. Ash.	CaO.	P_2O_5.	K_2O.	Total Urine in lb. per acre.	N.	K_2O.
FULL RETURN (Sampling Sheep only)	22/7/41-28/5/42	3902	131.0	498.6	166.4	151.0	67.9	42789	384.0	496.0
	Per cent.	—	3.36	12.76	4.26	3.87	1.74	—	0.90	1.16
NO RETURN (All collected)	22/7/41-28/5/42	2396	76.4	—	125.2	93.3	32.1	25603	210.4	274.0
	Per cent.	—	3.19	—	5.23	3.89	1.34	—	0.82	1.07
	21/5/43-30/5/44	2345	69.0	—	111.6	80.0	25.5	19067	190.1	191.3
	Per cent.	—	2.94	—	4.76	3.41	1.09	—	1.00	1.01
URINE RETURN (All Dung collected. Sample sheep only for Urine measurements 1st period)	22/7/41-28/5/42	2726	87.1	—	130.7	102.9	41.5	30884	301.8	409.1
	Per cent.	—	3.20	—	4.80	3.78	1.52	—	0.98	1.32
	21/5/43-30/5/44	2629	77.3	—	113.4	81.0	39.3	—	—	—
	Per cent.	—	2.94	—	4.32	3.08	1.50	—	—	—
DUNG RETURN (All Urine collected. Sample sheep only for Dung measurements 1st period)	22/7/41-28/5/42	2690	88.8	—	128.8	109.7	36.0	28607	252.8	329.6
	Per cent.	—	3.30	—	4.79	4.08	1.34	—	0.89	1.15
	21/5/43-30/5/44	—	—	—	—	—	—	19927	206.3	204.6
	Per cent.	—	—	—	—	—	—	—	1.03	1.03

The chemical composition of the dung shows similar trends as does that of the pasture, although the total soluble ash figures are, of course, much higher. This is clearly seen in the phosphorus figure for the 1944 summer period, where the extremely low figure in the pasture is matched by an equally low phosphorus content in the dung.

As mentioned, the urine was not analysed for calcium and phosphorus due to its very low content. The figures for nitrogen and potassium show fairly wide differences, and this is probably a combined effect of the differences in composition of the ingested food and the dilution from surface and other water.

TABLE IX. BALANCES BETWEEN MEASUREMENTS OF HERBAGE CONSUMED, AND NUTRIENTS PASSED BY THE ANIMALS

Treatment.	Period.	Total Nutrients in Pounds per Acre.							
		N.		CaO.		P_2O_5.		K_2O.	
Full Return	21/7/41-28/5/42								
	In Herbage	702.2		184.5		171.9		701.6	
	„ Dung		131.0		166.4		151.0		67.9
	„ Urine		384.0		*		*		496.9
	Totals	702.2	515.0	184.5	166.4	171.9	151.0	701.6	564.8
	Per cent. Balance	73.3		90.2		87.8		80.5	
No Return	21/12/40-21/7/41								
	In Herbage	242.8		89.3		57.7		207.4	
	„ Dung		67.8		89.8		70.1		28.2
	„ Urine		169.2		1.4		1.3		178.8
	Totals	242.8	237.0	89.3	91.2	57.7	71.4	207.4	207.0
	Per cent. Balance	97.6		102.1		123.6		99.8	
	21/7/41-28/5/42								
	In Herbage	492.9		154.0		116.4		408.5	
	„ Dung		76.4		125.2		93.3		32.1
	„ Urine		210.4		*		*		274.0
	Totals	492.9	286.8	154.0	125.2	116.4	93.3	408.5	306.1
	Per cent. Balance	58.2		81.3		80.2		74.9	
	20/5/43-30/5/44								
	In Herbage	449.2		142.4		102.6		321.7	
	„ Dung		69.0		111.6		80.0		25.5
	„ Urine		190.1		*		*		191.3
	Totals	449.2	259.1	142.4	111.6	102.6	80.0	321.7	216.8
	Per cent. Balance	57.7		78.4		78.0		67.4	
Urine Return	21/7/41-28/5/42								
	In Herbage	506.3		138.1		114.5		487.7	
	„ Dung		87.1		130.7		102.9		41.5
	„ Urine		301.8		*		*		409.1
	Totals	506.3	388.9	138.1	130.7	114.5	102.9	487.7	450.6
	Per cent. Balance	76.8		94.6		89.9		92.4	
	21/5/43-30/5/44								
	In Herbage	487.4		129.1		109.8		428.5	
	„ Dung		77.3		113.4		81.0		39.3
	„ Urine		†		†		†		†
	Per cent. Balance			87.9		73.8			
Dung Return	21/7/41-28/5/42								
	In Herbage	553.2		170.8		142.5		473.8	
	„ Dung		88.8		128.8		109.7		36.0
	„ Urine		252.8		*		*		329.6
	Totals	553.2	341.6	170.8	128.8	142.5	109.7	473.8	365.6
	Per cent. Balance	61.8		75.4		77.0		77.2	

* Not determined in analysis.

† No urine collections.

The results in Table IX represent an attempt to balance the measurements of ingested and excreted nutrients. Figures are presented for three years on the N.R., with one year on each of the others. The N.R. data are calculated from the complete collections of dung and urine on this treatment, whereas on the others, the results are obtained by the use of two sample sheep.

The balances illustrate some of the limitations of the experimental technique. The constituents which are excreted almost entirely in the dung, viz. calcium and phosphorus, show a reasonable degree of concordance (from 75-102 per cent. for calcium and from 74-124 per cent. for phosphorus).

Potash which is excreted to the extent of about 90 per cent. in the urine also gives balances in the same range (viz. 67-100 per cent.). The nitrogen balances are less satisfactory, the range being from 58-98 per cent.

There are several possible sources of error in the measurements of both ingestions and excretions by the sheep which could, cumulatively or separately, account for the differences found. These are :—

(a) The retention of some of the nutrients by the grazing animals for growth requirements could account for a small percentage, especially of the nitrogen. However, the sheep used were for the most part full-grown wethers and retention should not be great.

(b) There is a strong possibility of some retention as dung or urine by the sheep, due to the fact that it normally took much longer to harness up the animals than to unharness them. It is likely too, that the sheep were emptier when they went on to the block than when they came off, since the paddocks were not hard grazed at any time, while the sheep sometimes had come off fairly closely grazed areas.

(c) Quantitative urine collection is a difficult and laborious task, a point needing no elaboration to anyone who has attempted it. The fact that the balances for nutrients in the dung were better than those in the urine would suggest some loss of urine in the collection process itself.

(d) Urine samples held for analysis for periods of up to 2 months probably lost some nitrogen as ammonia. Herbivorous urine soon becomes distinctly alkaline in reaction and the loss of nitrogen as ammonia is suggested by the lower balance for nitrogen compared with potash.

(e) There is the possibility of a constant over-estimation of the ingested herbage by the cutting in the field. Although great care was always taken to do the cutting and hand plucking of the enclosed herbage down to the same stage as the grazing itself, this can be of course only an approximation. However, we feel that this point is not of such importance as the dung and urine losses, as normally such differences in cuttings tend to balance out over long periods.

Considered as a whole however, it is significant to note that with the exception of the phosphorus balance for N.R. in 1941, all the balances run the same way, and it is considered that the treatment differences can fairly be discussed in terms of pasture yields and compositions.

DISCUSSION

Most of the detail of the measurements in the trial have been discussed (1), and also comments have been made on each table supplied in the present paper. There remain some points on the overall results of the trial which merit repetition. Firstly, there is the very high and sustained yield on the N.R. treatment over the four year period. This has undoubtedly resulted from the exceptionally good growth of the pedigree white clover used and the fact that it was apparently adequately fed with the added phosphate and lime. Also because of the apparently high potash resources of the soil, non-return of this did not appear to cause any drop in production. Trials are at present under way at Palmerston North to obtain more detailed data of the effects of limiting certain of the minerals in such a soil as well as the influence of the clover itself.

Secondly there are the sustained increases in yield when the dung and urine are returned and the interesting combined total effect of these two together. The quick response by the grass to the return of urine is reflected both in the yield and composition. This effect, however, appears to have fallen off in intensity later in the trial, perhaps due to the drain in phosphate of the removed dung, which could have made less effective the nitrogen in the urine. However, there is no definite evidence of this from the trial results themselves.

The effect of the dung is clearly seen with its relatively slow build-up of the pasture sward from the stage of clover dominance to one of grass dominance, although even in the later stages there were still periods of poor grass growth. The return of the dung resulted in no loss of soil nutrients which are normally in short supply, viz., calcium and phosphorus, whilst an increase in soil nitrogen would follow both the strong growth of clovers and the more slowly available nitrogen of the dung itself. The loss of the nitrogen of the urine was reflected in the relatively slower growth of grass but the withholding of potash was probably not continued long enough to effect any limitation of pasture growth.

The trial does not give any clue as to whether or not the added phosphate and lime was necessary or beneficial, but, as the average annual extra uptake of phosphorus was only approximately 27 lb. it certainly does not appear to have been so.

Where both the dung and urine were returned, the total plane of production has been raised by 33 per cent., while the botanical composition is stabilized as a ryegrass dominant sward. The combined effect of the quick-acting urine and the slower but sustained dung effect is clearly seen. Again, there is no evidence of the real value of the added minerals, but it appears probable that for the grazing conditions of this treatment, much less added phosphate and lime could be used without loss of production. This, however, would need to be worked out under actual field trial conditions, using different classes of wet and dry stock with their varying mineral requirements for growth or production.

It is of interest to consider the nutrient turnover in the F.R. pasture and the manurial values determined for the mature dry stock used in the trial. For an average annual pasture yield of 14,000 lb. dry matter per acre, the quantities of the nutrients contained in the pasture sward expressed in terms of fertilizers are as follows :—

Nitrogen (N) equivalent to 27.9 cwt. sulphate of ammonia.
Calcium (CaO) equivalent to 2.4 cwt. carbonate of lime.
Potassium (K_2O) equivalent to 17.1 cwt. 30 per cent. potash salts.
Phosphorus (P_2O_5) equivalent to 6.5 cwt. superphosphate.

Of this amount, using dry sheep, and subject to the errors of the trial, we accounted for the following amounts actually contained in the dung and urine :—

Nitrogen (N) equivalent to 20.5 cwt. sulphate of ammonia.
Calcium (CaO) equivalent to 2.2 cwt. carbonate of lime.
Potassium (K_2O) equivalent to 13.8 cwt. 30 per cent. potash salts.
Phosphorus (P_2O_5) equivalent to 5.7 cwt. superphosphate.

As mentioned in the text these calculations are from the two pilot sheep on the F.R. treatment for the 1941 season only. It can be seen that much higher figures were obtained on some of the other blocks, but even so the amounts as shown do give a striking picture of the manurial value of, and the great need to utilize to the fullest advantage, the dung and urine produced by the grazing animal.

Looked at from the angle of the nutrient drain under conditions of no return of dung and urine, the quantities removed per acre per annum are as follows. For the average annual pasture yield of 10,600 lb. of dry matter, with a different botanical and chemical composition, the drain in terms of fertilizer is :—

Nitrogen (N) equivalent to 20.6 cwt. sulphate of ammonia.
Calcium (CaO) equivalent to 2.7 cwt. carbonate of lime.
Potassium (K_2O) equivalent to 11.9 cwt. 30 per cent. potash salts.
Phosphorus (P_2O_5) equivalent to 5.3 cwt. superphosphate.

The fact that the above trial was carried out on soil originally high in soil nutrients and under good climatic conditions undoubtedly accounts for the high yield of plant nutrients, and the practical interpretation of the results of the experiment must be made accordingly.

Thus it would be expected that the effects of dung and urine would be more marked on land which is not adequately supplied with the nutrients considered. This applies not only to the phosphate and lime which were applied liberally to all treatments of this trial, but also to the potash which apparently was satisfactory in the soil worked on, but which is passed in such large quantities through the soil-plant-animal cycle. Provided that other nutrient requirements are reasonably well catered for, it would appear from this trial that the nitrogen-fixing capacity of vigorous clovers is adequate to support good grass growth without nitrogenous topdressing, except for particular out-of-season needs. Trials are at present under way at Palmerston North to measure the effect considered in this trial, on pasture devoid of clovers, and on pastures of grass and clover not supplied with fertilizers as was this trial here reported.

For the overall practical implications of the effects of animal excreta on the pasture and the need not only for efficient conservation but also for a grazing management which will ensure the best redistribution on the farm, we refer to the foreword in the original paper.

There is little doubt that in New Zealand, both on flat land and on hill country, there is ample scope for improvements in grazing practices centring round the need to obtain the fullest redistribution of animal droppings. This will only come about when the farmer himself is made fully aware of the enormous fertility value of the excreta passed by the grazing animal. Linked with this would be carefully considered feeding out of silage, hay, and forage crops so that parts of the farm are not depleted of soil nutrients, without thought or care being given to the

manurial return. Also, greater attention would be given to the fertilizer programme both on hill and flat country where, because of the grazing habits of the animals themselves, soil nutrients are transferred as dung and urine from one part of the paddock to another or from one part of the farm to another.

In all such cases, it follows quite logically that the application of fertilizer "from the bag" should be made to the depleted areas.

It is only by following such practices that balance is secured in the soil fertility level both of the paddocks as units, and the farm as a whole.

ACKNOWLEDGMENTS

The authors wish to acknowledge the assistance given by Messrs. Morrison, Andrews and Taylor in the field work, to Messrs. Fraser and Turner in the chemical analytical work, and to Mr. E. Bruce Levy and Dr. J. Melville, Directors of the Grasslands Division and Plant Chemistry Laboratory respectively, for continued interest and assistance.

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FERTILIZER BY FUSION OF ROCK PHOSPHATE WITH GREENSAND AND DOLOMITE

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Summary

Fusion, under reducing conditions at comparatively low temperatures, of rock phosphate with approximately its own weight both of roasted greensand and of limestone or dolomite, produces a soluble silico-phosphate slag comparable in composition with basic slag, and containing also a small proportion of available potash. This slag can also be used to cause "reversion" of superphosphate.

INTRODUCTION

THE recent discovery by Macpherson (1) of a very large and accessible deposit of glauconitic rock in the North Island (at Otaihanga, near Paraparaumu) revives interest in the possible use of such greensand as a source of potash. Glauconite, of which high-grade greensand is almost entirely composed, is a silicate of iron and potassium containing approximately 20 per cent. of ferric oxide, 6-8 per cent. of potash, 50 per cent. of silica and 10 per cent. of combined water with minor amounts of alumina and magnesia. Roasting at 800°C. increases its potash content and prevents "sliming" in grinding, by expelling combined water.

Many attempts have been made to extract potash from greensand, varying from decomposition by sulphuric acid (2) to fusion with limestone and salt, while there have also been many attempts to make the phosphoric acid of rock phosphate more available to plants, ranging from the traditional use of acid to fusion with alkali or natural silicates such as olivine rock (3). However it seems from the literature available, that there has been no attempt to incorporate both the potash of glauconite and the phosphoric acid of rock phosphate into a soluble silico-phosphate slag by simply using the greensand as a flux for the rock.

Experimental

By preliminary small fusions of Nauru rock-phosphate, high-grade roasted greensand and marble with an oxy-acetylene torch on a graphite crucible-lid, it was found that, when the proportion of calcium carbonate was gradually increased to slightly more than one part by weight to one part greensand and one part rock, the mixture, while still readily fusible, gave a glassy green slag (containing occasional small globules of iron) which was now easy to grind, alkaline to phenolphthalein, and completely soluble in cold 2 per cent. citric acid solution. When the crushed slag was added to water through which was passed a slow stream of washed CO_2, approximately 16 per cent. of it, with a corresponding proportion of the phosphate, passed into solution overnight. This suggested the possibility of forming, under reducing conditions, at temperatures approximating those of a Portland cement kiln, a soluble slag comparable in P_2O_5 content with a good basic slag, and containing in addition about 2.5 per cent. of potash (K_2O).

It was found also that when dolomite replaced limestone in the mix rather less was needed and the mixture seemed more fusible.

Larger Fusions.

Larger quantities of mix (about 45 g.) were next heated, under more controllable conditions, in a fireclay crucible within a gas-fired ash-fusion furnace. Two experiments were then carried out :— (a) in which 1.1 parts of marble, (b) in which 1 part Collingwood dolomite, were heated with 1 part each of roasted Otaihanga greensand and rock phosphate, in a reducing atmosphere to 1,400°c. There resulted a very mobile slag (Fig. 1) cooling to a yellow-green translucent glass, which crushed to a very light green colour. In the standard A.O.A.C. test for citric acid solubility of phosphatic slags, in (a), 6.6 per cent. and in (b), 2.2 per cent. of the slag remained undissolved. These residues

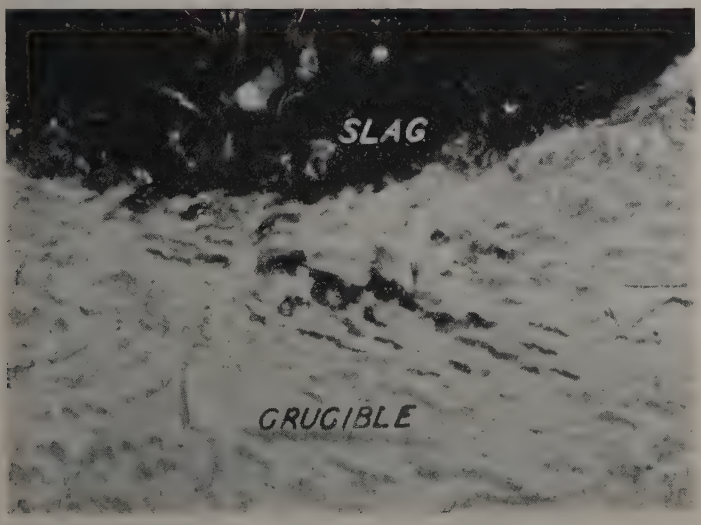

Fig. 1

contained approximately: (a), 15 per cent. and (b), 5 per cent. of the total P_2O_5, but no silica. The insoluble residues thus consisted, not of slag, but of the coarser particles of phosphate-rock, which had not been taken up and absorbed in the melt, and so later remained when the silicate slag itself dissolved in acid. On similarly heating another mix (containing 1 part dolomite) after first grinding its rock phosphate to pass a No. 100 British Standard Sieve, over 98 per cent. of the resulting slag passed into colourless solution while the residue contained much less than 2 per cent. of the total P_2O_5 (which amounted to 13.6 per cent. of the slag). Thus the first requisite for P_2O_5 solubility is that the rock phosphate be thoroughly dissolved in the slag, making the slag itself, and with it the contained phosphate, entirely citric-soluble. Possibly a second essential, were the slag made in larger bulk, would be sudden cooling to prevent recombination of fluor-apatite.

Oxidizing and Neutral Conditions of Fusion.

Since it was found that the total P_2O_5 content of the slags formed under reducing conditions as above was approximately only 85 per cent. of the amount expected, an attempt was made to reduce this loss of phosphorus through volatilization by heating the mixture (1 part dolomite) to 1,400°c. in an oxidizing atmosphere. The hot melt, which was now much less mobile, cooled to a duller and less translucent glass, somewhat vesicular, and of brown colour on crushing. In this slag, total P_2O_5 amounted to 14.6 per cent.—about 95 per cent. of the calculated value—but in the citric acid test only 72 per cent. of the slag, passed into yellowish solution, and the 28 per cent. residue was highly phosphatic. Even when the same mixture was heated in a neutral atmosphere to 1,400°c., the dull glass produced, which was slightly magnetic, and blue-grey in colour when ground, was almost equally disappointing in solubility. It appears that the greater fluidity and therefore greater dissolving power of the hot ferrous silicate slag produced under reducing conditions is essential for the absorption of the phosphate and for the citric solubility of both slag and contained phosphate. That only the ferrous slag is citric soluble is also shown by heating some of the crushed green glass in air, when it turns red by oxidation, and becomes quite insoluble. It is perhaps significant that in basic slag itself there is actually more ferrous oxide than here, as shown in the following comparison of the composition of an average basic slag (4) with that of the slag formed by fusing equal parts of rock phosphate, roasted greensand and dolomite in a reducing atmosphere : –

	Basic Slag	Silico-Phosphate Slag*
CaO per cent.	42	31.1
MgO ,, ...	6	8.3
Al_2O_3 ,, ...	2.5	3.0
Fe_2O_3 ,, ...	8.5	0.9
FeO ,, ...	13.5	8.3
SiO_2 ,, ...	8	30.2
P_2O_5 ,, ...	15	13.5
K_2O ,, ...	Nil	2.3

* Made by fusing together, without precaution against loss of phosphorus through reduction and volatilization, equal parts Nauru phosphate, roasted Otaihanga greensand and Collingwood dolomite.

Low Melting Point under Reducing Conditions.

As the preliminary experiments described above indicated that reducing conditions are essential, further investigations were confined to these. The melting point in a reducing atmosphere for a mix containing 1 part dolomite as determined on a cone of the material by optical pyrometer and Seger cones, was under 1,250°C. This suggested that perhaps 1,400°C. was an unnecessarily high temperature for fusion, though still low compared with the 1,450°-1,550°C. required for fusions with olivine rock (3). When, however, such a melt was held at 1,300°C. in reducing atmosphere for half an hour, it was found not to be fluid, the resulting glass was only 88 per cent. soluble, while the 12 per cent. residue contained at least 25 per cent. of the total P_2O_5. It thus seems that a temperature of 1,350°-1,450°C. is actually needed, not perhaps directly to break up the insoluble fluor-apatite molecule, but rather to make the slag sufficiently mobile to attack the phosphate and thus dissociate it. It is likely that a small proportion of boric acid in the mix (added as borax or as boron-containing coal-ash) could be used to lower this temperature considerably, so long as it did not make the molten slag too aggressive to furnace linings, or the resulting glass insoluble.

POTASH CONTENT

The K_2O content of the soluble slag was found to be 2.25 per cent. while 1.4 per cent. could be extracted with cold 5 per cent. acetic acid.

REVERSION

The alkaline soluble slag causes complete reversion, when mixed, warm and moist, with an equal weight of superphosphate. The resulting compound contains 17-18 per cent. P_2O_5 and slightly over 1 per cent. K_2O with 15-16.5 per cent. P_2O_5 citric soluble, and is thus superior to the serpentine superphosphate (5) previously suggested by the author, in that it contains slightly more P_2O_5 and an appreciable amount of potash.

POT TESTS

Outdoor pot trials were carried out with the slag using blue lupins in Maunu (N. Auckland) basalt soil (kindly supplied by Soil Bureau, D.S.I.R.) which is somewhat phosphate-fixing, although fairly fertile. The trials were done in triplicate while the control pots contained, like the others, 0.5 g. ammonium nitrate plus 10 g. calcium carbonate. Although, as indicated in Fig. 2, phosphate-response was not high, it showed up at least as well for slag as for superphosphate or serpentine superphosphate. (A remarkable feature of these trials on Maunu soil, in spite of liming, was the uptake of manganese in all four cases—namely 0.4-0.5 per cent. Mn on the ash, or 400-500 parts per million on dry weight.)

CONCLUSIONS

1. It seems that reducing conditions are required for producing, at comparatively low temperatures, slags of high citric solubility. Such conditions involve increased danger of loss of phosphorus, but in the Tennessee Valley Authority fusions of rock phosphate and olivine rock, where the carbon of the arc and furnace linings gave reduction at 1,450°-1,550°C., this loss was prevented by continuous working of the furnace, so that a cover of unfused charge above the molten material acted as an absorbent trap for vapours of P or P_2O_5 (3). The danger of loss is also lessened in our case by the lower fusion temperatures permitted.

FIG. 2.

Control (C). Dry wt. 4.16 g.	C + Super. 5.47 g.	C + Serp. Super 5.27 g.	C + Slag. 5.68 g.

2. The incorporation of a small percentage of potash in the slag not only increases its value as a fertilizer but is also helpful as a flux ; indeed perhaps the main advantage gained by including greensand in the fusion lies in the possibility of producing at moderate temperatures and from plentiful native materials, a citric-soluble slag not unlike the best basic slag. This is the form of fertilizer in which phosphate is likely to be most effectively and economically expended, especially for pasture on acid, magnesia deficient, or phosphate-fixing soils—a claim which can be tested by producing the slag in quantity sufficient for pot and field trials.

EVIDENCE OF MOBILITY OF THE SLAG DURING FUSION

Indication of the highly fluid nature of the slag at 1,400°C. is its invasion of the spun fireclay-and-grog material of the assay-crucible, as illustrated in Fig. 1 where crucible and contents have been cooled and then broken across.

POT TEST, USING BLUE LUPINS

Growth outdoors in Wellington in 3 months August-October, 1947, with 0.75 g. of each fertilizer per pot of 500 g. soil.

ACKNOWLEDGMENT

The writer wishes to thank the Dominion Analyst for permission to publish this paper.

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REVIEW

SVALOF 1886-1946; HISTORY AND PRESENT PROBLEMS

Edited by A. Akerman, Ph.D., O. Tedin, Ph.D., K. Froier, Ph.D. English Technical Editor, Dr. R. O. Whyte. Lund, 1948. 389pp. 30s.

"The purpose of the present book is to present the activities of the Swedish Seed Association in the hope that such a presentation may intensify the international connexions of the association." In these words Lindberg, after outlining the work of the Cereal and Chemistry Laboratories, returns to the theme of the preface in which the editors stress the value of personal contacts between plant breeders from different parts of the world.

As the Swedish Seed Association was founded in produce crops and pastures especially adapted to Swedish conditions, the papers outlining the practical achievements in individual crops are of limited interest to us in New Zealand. Of considerable interest, however, are the general papers which outline the history and, to some extent, the theory of the breeding methods employed at Svalof:

The Breeding of Self-fertilized Plants by Crossing, by A. Akerman and J. MacKey.

Natural Selection and the Breeding of Cross-fertilized Plants, by G. Nilsson-Leissner.

The Cyto-Genetic Department, by A. Levan.

Experiences from Work with Induced Polyploidy in Cereals, by A. Muntzing.

Mutation Work at Svalof, by A. Gustafsson and J. MacKey.

These authors are all well known for their papers in many scientific journals, and those accustomed to follow their work may be disappointed by the brevity of the theoretical discussions. For example, Akerman and MacKey's condensed account of the effect of Rasmusson's interaction hypothesis on the interpretation of frequency curves of yield data would only confuse readers who were not familiar with the theories discussed, while failure to mention developments of the interaction hypothesis later than those of Rasmusson, raises doubts in the minds of others. However, the accounts given show the way in which methods now used at Svalof have been developed and how the practical breeders of Svalof make use of recent advances in cytology and genetics. How they also contribute to advances of fundamental theory is not discussed, but the bibliographies, especially that at the end of Levan's article on the work of the Cyto-Genetic Department, list theoretical and practical papers by members of the staff.

As a means of strengthening international contacts, the final paper, discussing the availability of publications from Svalof, is useful.

The English translation has been made with great care and the book is excellently printed and produced.

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